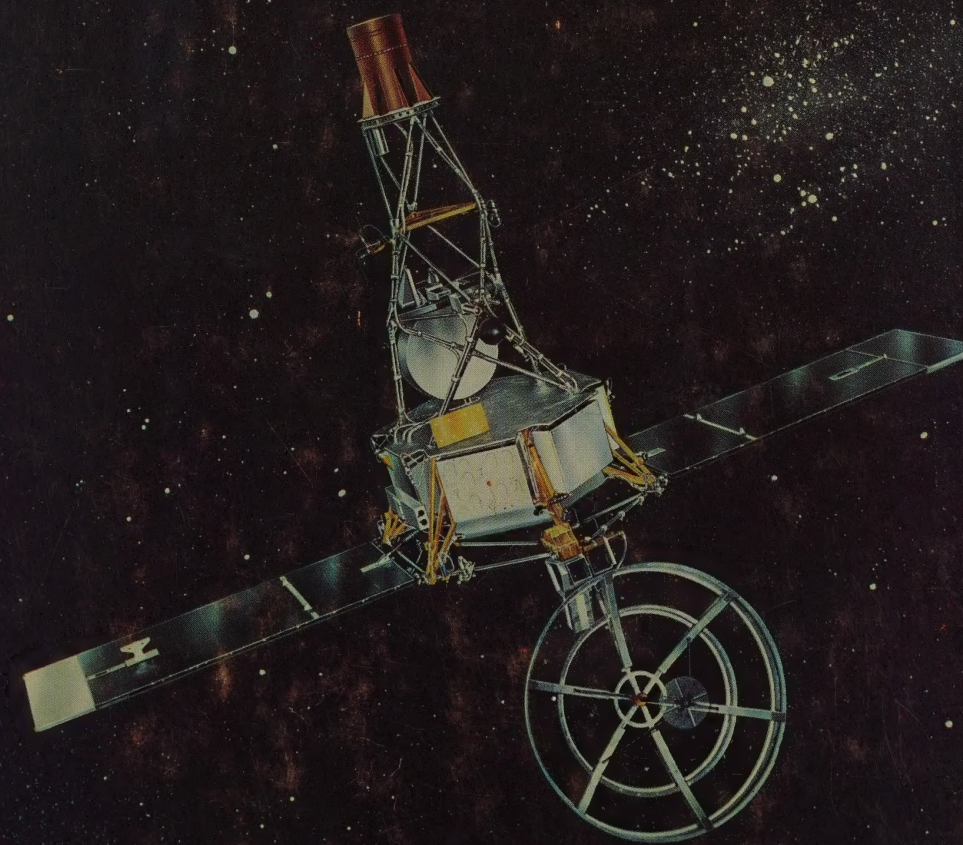


ELECTRONICS

KEY TO EXPLORING SPACE

ROBERT WELLS



**HOW SCIENTIFIC INFORMATION IS SECURED IN
SPACE AND COMMUNICATED FOR USE ON EARTH**

ELECTRONICS

Key to Exploring Space

by Robert Wells

Illustrated with photographs

Man searches interplanetary space, exploring that vast unknown region in preparation for the day when he himself will go there in person. He seeks knowledge, and his means of securing it is through electronics—the understanding and use of electromagnetic energy.

The instruments aboard a space vehicle—radiometers, magnetometers, cosmic dust detectors—are electronic devices, as are radio, radar, television cameras, and indeed man himself. His understanding of electromagnetic forces has been put to use in his scientific tools.

Robert Wells, author of numerous volumes about the space age, explains how it is done, discussing computers and their binary language, telemetering of data, commands to spacecraft, radio astronomy, sensors and lasers, as well as how space projects like Ranger and Mariner are developed.

What has been achieved is astounding, and with enough information gained about those other worlds, man will reach his goal in space. The key to obtaining that vital knowledge is electronics, and he holds the key.

*Jacket photograph courtesy of
Jet Propulsion Laboratory,
Pasadena, California*

Electronics, Key to Exploring Space

By ROBERT WELLS

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WHAT DOES A CIVIL ENGINEER DO?

WHAT DOES A JET PILOT DO?

WHAT DOES AN ASTRONAUT DO?

WONDERS OF FLIGHT

Electronics,

KEY TO EXPLORING SPACE

By ROBERT WELLS

ILLUSTRATED WITH PHOTOGRAPHS

DODD, MEAD & COMPANY

NEW YORK

to
JAD
my editor
with thanks
and admiration

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—ROBERT WELLS

Preface

Only a very few years ago, the title of this book, *ELECTRONICS, KEY TO EXPLORING SPACE*, would have been fanciful. A few years before that, the same title would have been meaningless. Today, both space and electronics are words that still carry a sense of the magic of expanding frontiers. Before long, both will be as well understood as today's internal combustion engine.

We make ingenious use of electrons, one of the smallest particles, to explore the largest thing we know how to name—the cosmos. Our understanding of both electronics and space is growing as each discovery, each technique leads to more of that organized inquiry we call research. We do not have the answers now about either our tools of exploration or the subject of that exploration—but we are learning.

A spacecraft operating properly a quarter of a million miles away is not a lonely ship cut off from the world.

Preface

It is rather an integral part of a very complex and delicately balanced system made up of men, ideas, ground equipment, and flight hardware. Our explorations today require a closed loop, with the miniature electronic measuring and control instruments in the spacecraft matching the large and powerful systems on the ground.

Information gathered in space is useless unless it can be sent intelligibly back to the ground; even there, it must be decoded and analyzed before a concrete fact can be distinguished from the many theoretical possibilities. By trying to keep the heaviest and most complex parts of a total exploration system on the ground and sending out into space only the lightest and most rugged parts of that system, we are able to make the best use of what our technology provides.

It is important to realize that each space mission is really part of a single system, separated from its other parts by space but linked by electromagnetic energy. It is the growing miracle of electronics that makes this possible.

This miracle has a long history, bridging the distance between Franklin's kite and Project Mercury. It is only recently that the major advances have been made—and they are still being made daily. Scientists, researchers, engineers, and backyard inventors contribute steadily to the field of electronics, working at universities, in laboratories, in industry, or for the Government. At the same time, these new electronic tools are being taken

Preface

as fast as they are delivered and are being used to begin the primitive exploration of our universe.

This volume is most appropriately titled, in that without electronics, man could not today be looking at space as a frontier but would have to be satisfied with the limits of his own world.

—EDMOND C. BUCKLEY
Director, Office of Tracking
and Data Acquisition
National Aeronautics and
Space Administration

Contents

PREFACE by Edmond C. Buckley, *Director, Office of Tracking and Data Acquisition, National Aeronautics and Space Administration*, vii

1. The Search, 1

What the Astronomer Sees, 4

Atom and Universe, 8

Electromagnetic Energy, 9

2. Space, Earth's Cradle, 12

Sun, Earth, and Electromagnetic Energy, 12

Electromagnetic Energy and Extraterrestrial Life, 14

Man in the Search, 16

3. Exploring Other Worlds, 20

Exploring the Moon, 21

- Clues to Earth's Beginning, 23
- Exploring Elsewhere, 23
- 4. What's in Space? 26**
 - Stormy Seas in Space, 27
 - The Solar Wind of Space, 29
- 5. Steps into Space, 31**
 - The Spectroscope, 32
 - Levels of Exploration, 33
 - The Ultimate Instrument, 38
- 6. Man and Other Space Instruments, 39**
 - Scientific Instruments, 40
 - Biological Instruments—Biosensors, 42
 - Engineering Instruments, 44
- 7. Theories into Space Projects, 46**
 - Selecting the Experiment, 47
 - The Instrument's Delivery Vehicle, 48
 - Controlling the Instruments on Board, 50
 - Missions and Projects, 51
- 8. Mariner—Its Experiments and How They Work, 54**
 - Mariner II's Objectives, 55
 - The Microwave Radiometer, 56
 - The Infrared Radiometer, 58

Contents

- The Magnetometer, 59
- The Ionization Chamber, 60
- The Geiger-Mueller Tubes, 60
- The Cosmic Dust Detector, 61
- The Solar Plasma Detector, 62

- 9. Ranger, Moon Sleuth, 63**
 - A Ranger Mission, 65
 - The Instruments, 67
 - The Follow-on Projects, 71

- 10. Seeing Stars—by Radio, 72**
 - Radio Astronomy, 73
 - Radar Astronomy, 76

- 11. Electronic Communications in Space, 79**
 - How Radio Works, 80
 - How Radar Works, 84
 - How Television Works, 84

- 12. Space Brains—Electronic Computers, 86**
 - The Digital Computer, 87
 - Computer Language, 88
 - How a Computer Works, 89
 - Computer in the Command Link, 90

- 13. Telemetry: What, Why, How, 93**
 - Biosensing and Telemetry, 97

14. Command: Remote Control of Spacecraft, 101

Types of Commands, 102

Antenna, 103

Command Sites, 105

Sending the Command, 106

Commands and Accuracy, 107

Commands to an OAO, 108

Commands to a Moon Soft-Land, 109

15. Tracking a Spacecraft, 111

Equipment, 112

Doppler, 113

Range and Direction, 115

Data Acquisition, 117

Optical Tracking, 119

Communications Net, 119

Manned Interception of Manned Spacecraft, 121

16. It Looks Easy . . . , 125

Design Problems, 125

Power-Distance Requirements, 128

Space Damage, 129

Reliability, 130

Attitude, 130

Radio Interference, 131

Distance-Time, 132

Frequency Shortage, 132

Power-Time, 133

Contents

17. Problem Solving, 135

Solar Panels, 135

Coding, 136

Frequency Shortage, 137

Relay, 138

The Laser, 139

The Diode, 142

Reliability, 143

Achievement, 144

18. New Approaches to Old Problems, 145

Computer, 146

Saving Time and Work, 146

Interest in Only the Exceptional, 147

Manned Spacecraft Rendezvous, 148

Power Sources, 149

19. Applications of New Knowledge, 151

Electric Propulsion, 151

Other Applications, 152

APPENDIX, 157

Communications Satellites, 157

Navigation Satellites, 162

Weather Satellites, 164

Orbiting Observatories, 167

What Venus-Probe Mariner II Found, 168

INDEX, 171

Illustrations

Following page 80

The laser; Electromagnetic frequency spectrum

An area in space viewed at different wavelengths of different
colors

Geophysical and solar studies

Exploring interplanetary space

Data acquisition and transmission; Detection of extraterres-
trial life

Components of the Ranger spacecraft

Ranger flight plan

Mariner II evolution; Surveyor A

Miniature electronic computer; Gyroscopes for flight control
of Tiros II

Millstone Hill radar

Radar map of moon's surface radio-activity

Illustrations

Mariner spacecraft

Mariner midcourse maneuver

Facsimile of Mariner II tape

Mercury tracking station; Deep space tracking radar at
Woomera, Australia

Testing biosensors; Helmet microphone of Astronaut Walter
Schirra

The Search

No shipload of explorers ever quested for greater treasure from a stranger land than this spaceship-load of scientist-astronauts negotiating their craft in the first manned landing upon the unnatural surface of another planet.

The treasure they seek is information. Some of this information is recorded electronically on tape within the craft. Some is radioed, some televised. At a base established years earlier on the Moon, men intently monitor their electronic receivers of this information. On their television screens the other world's surface grows clearer and more detailed as the spaceship nears it. Jagged blue-green lines dance abruptly across the latticed glass face of oscilloscopes. Earphones sing a monotonous, insistent beep-beeping. A computer spews

Electronics, Key to Exploring Space

out a printed paper record of seemingly unintelligible letters and numbers. On Earth, other men monitor more, larger, similar instruments. These, too, receive this information whose electronic signals are boosted in power by the communications instruments and men at the Moon Base, and then relayed.

Information, many kinds of it, has made it possible for these scientist-astronauts to be so surely settling their craft farther away from Earth than man has ever traveled before. Some of that information was obtained from earlier probes, from fly-by's of the planet, from similar ventures to the Moon where the Moon Base has been established. Now man himself prepares to close the few remaining yards between his spacecraft and the unfamiliar surface.

Men search the vastness of space, seeking more and more information. They plan to go to the Moon, to land on other planets in their quest for knowledge. Their search is only a part of the big search: What is our Universe comprised of? And our Solar System? And our own Earth, that little rock hurtling through space at some sixteen miles a second?

Information already obtained makes it possible. The strange surface of a far-distant planet will be unfamiliar, yet familiar. Man, going in person at last, will have been there all *but* in person. Extensions of his own eyes and brain were there earlier. Unmanned spacecraft landed

there. Their sensors perceived and reported to their "brain," their computer.

Information was radioed or televised from these unmanned craft. Some transmissions were automatic, triggered by time or by distance from that other world's surface. Some transmissions were commanded, remotely, by men monitoring these experiments from spaceships circling above, not yet ready to attempt a landing.

This intelligence—of the planet's surface structure, its atmosphere's temperature and pressure, its magnetic fields and radiation hazards—confirms or corrects reports from earlier probes. These had not reached quite as far nor reported quite as accurately. The later, landed unmanned probes succeed in their missions because of information secured earlier by less sophisticated, less far-reaching probes. Each successful step which finally brings men safely to the surface of another world is a step just a little longer and a little more sure than the step taken just before.

And so men search—electronically, via sensors and computers and via their own senses and brains—for new information. It is this new information, added to information already secured and that yet to be secured, that at last will form answers to their questions about their Universe and the space which contains and comprises it.

Their eyes look and perceive; the sensors of their craft also perceive, and report their perceptions. And in this

Electronics, Key to Exploring Space

perceiving, both man and instrument work by means of the same kind of energy—electromagnetic energy.

What the Astronomer Sees

Some of this information came to hand thousands of years ago. It started when men first lifted their eyes and noticed the stars, and then began to wonder about them. With no facility other than their own eyes and brains they observed movement by these stars, these points of light that appear in the night sky. They observed more closely and discovered the *orderliness* of that movement. And then they were able to do even more: they calculated that movement, and predicted it. Some mathematicians of ancient Greece concluded, but had no means of proving to their own complete satisfaction, that the Earth is round, that the Sun's size is as enormous as it actually is, and that the Sun is some ninety millions of miles distant.

But when astronomers were given the telescope to work with, they were able to observe more accurately. They could see in more detail, more truly, and more deeply into the vastness of space. Old information was re-examined and errors were discarded. Accuracies were expanded and then used for evaluating this newly acquired information. And this new information—the part that was then proven accurate—was itself put to use as

a tool in the search for still more, still newer, still more accurate information.

They made their telescopes larger and better, and peered into—even photographed—great cones of lightless, cold space so vast that its millions upon millions of stars are all but lost in it. They looked at, then far beyond, Earth's sister planets and their moons revolving about our Sun. They looked at and beyond the Sun itself—that star which, though ninety-three million miles distant, so closely affects all life on our planet.

Light from heavenly bodies far more distant than members of our own Solar System is caught in the lenses of telescopes, gathered and focused into a compressed and thus very bright, sharp, but still true image. This is the image presented to the astronomer's eye whose lens, in turn, focuses that bright spot of light into a still smaller image and presents it, now pin-prick in size, to nerve endings inside his eye. Betelgeuse, a star so enormous its diameter would occupy Earth's orbit around the Sun, is compressed to a pin-prick on a few nerve endings of his eye—yet so *truly* that it nevertheless is instantly recognized by his brain to which these nerve endings connect.

In something of the same way, electronic “brains” (computers) “recognize” the essentials of what their “eyes” (sensors) “see” and report to them. And in this process of perceiving and recognizing, it is electromag-

netic energy that makes it possible—for man or for instrument.

From still other reaches in space come more of these dancing waves of electromagnetic energy, pulsing at millions of millions of times each second. These waves that we know as light reveal, through telescopes that grow larger and more accurate, great clusters of stars. These continue uninterrupted, even beyond the range of four billion light years that the lenses of these instruments can gather their rays of electromagnetic energy. (And already there is promise of extending this great range to ten or even *twelve billion* light years.) If a star or another celestial body had come between, these rays would not have reached the eye that beheld them; yet even at so great a distance, no star did intervene, so vast is space and so empty.

So empty, only because it is so vast; for space holds stars so many that we number them by the billions of billions without seeing an end. There are stars, like our own Sun, with their own planets revolving around them. These planetary systems group by the millions into galaxies like our own Milky Way. Our Milky Way is a mediocre galaxy; to traverse it from edge to edge would require only some 100,000 years of travel at the speed of light—186,000 miles per second.

Some 35,000 light years from this galaxy's center and revolving around it at about 675,000 miles per hour is our Sun. Accompanying the Sun is our Solar System.

Pluto, outermost planet of the Solar System, is 5.5 light hours from the Sun, but Earth is much nearer—only 8.3 light *minutes* away, while our Moon's distance from us is a scant 1.3 light *seconds*. Here is our location, all but lost in one of this galaxy's spiral arms. And galaxies are gathered into groups of galaxies—groups apparently without number.

This is what man wishes to investigate.

By what presumption does he mean to attempt this? And why?

Some would say that his curiosity has always sent him into the unknown and led him to find ways of exploring it. Others say that he explores space for the same reason he climbs a mountain—simply because it is there. There are others who would explore space hoping for immediate “practical” rewards: valuable new substances, or new techniques and new materials which are evolved in the process of exploring, or new and better conditions to carry on manufacture or research requiring the vacuum of space rather than Earth's environment of pressure, temperature and other interferences.

There are still others. They would seek to learn the structure and operation and origin of our Universe, our world, ourselves. If questioned about the “practical,” perhaps they would answer with another question: Who knows what practical benefits may come *incidentally*, as by-products, in this search for information which reaches out so far and which may lead who-knows-

Electronics, Key to Exploring Space

where? Their concern is a search for basics. And as for the "practical," who is to say that their "long way round" may not after all prove to be the "short way home"?

All, however different their approach, are faced with the same conditions, faced with the same problem for gaining accurate information. In these endless deeps of countless worlds—some hot and young, some cold and old, some the size of Betelgeuse or larger, and some smaller than Mars' moon Phobos that is only five miles in diameter—and in the reaches between these bodies, containing traces of dust, radiation, electromagnetic emissions from stars (or is it from *between* stars?), are a diversification and an endlessness so great that surely men must despair ever to find even a thread of certain knowledge. How can they hope to reach the goals of their search, whether it is to learn the measurable "What's out there?" or the dim "How did it all begin?"

How, indeed?

Atom and Universe

They can succeed because of several pieces of information already gained. One is the recognition of the orderliness of the Universe, in its structure and in its functioning. This alone, once it is observed and charted, makes it possible to speculate and even to predict.

Another piece of information reduces the complexity of the search, and again it has to do with orderliness. It

is the knowledge that atoms are the stuff of our Earth and all that is in it or on it, including ourselves. Even more, atoms comprise whatever is solid not only in our world but also in our Universe.

And we know what comprises an atom.

We know thus far that the atom has a nucleus and that electrons revolve around it. There is only one electron in the hydrogen atom, which is the simplest atom and by far the commonest throughout the Universe. Various combinations of electrons within the atom are what make up the different kinds of atoms; and these atoms comprise the different elements. In all these atoms, the electrons revolve around the nucleus.

Earth, made up of atoms held together so tightly that we can stand on them, revolves around the Sun in company with the other planets. And this system whirls with its galaxy as that, too, revolves around its own center. The force of gravity helps hold Earth and its sister planets close to their Sun, and the Sun within its galaxy, and the galaxy as a group—of some one hundred billion stars. From atom to galaxy—here are patterns, instead of unpredictable chaos.

Electromagnetic Energy

Inside the atom there is an even stronger force than gravity—billions of times stronger. It holds the circling

Electronics, Key to Exploring Space

electron close to the nucleus, and thus structures the atom. It is *electromagnetic* force.

From our Sun come waves of electromagnetic energy. These produce light. They provide the energy of life in Earth's creatures, and in the vegetation these eat for life's energy. Perhaps the same kind of electromagnetic energy also provides the life energy—radiated from other suns—for other forms of life elsewhere in our Universe, if indeed such life does exist.

It also is electromagnetic energy, although man-made and less intense, by which man's radio transmitters broadcast their messages of information, of intelligence. And it is, very largely, electromagnetic energy that is used by specially designed instruments to "sense" physical conditions existing in space. These special instruments, called *sensors*, can measure temperature, or measure the force by which miniature meteors speed through space, or measure the strength of magnetic fields surrounding Earth or other planets, or measure the dosage of harmful parts of the Sun's radiation that would destroy a man not protected from them by atmosphere on Earth or by shielding in space.

Electromagnetic energy—what better, more useful tool could there be for investigating space? Here is a kind of common denominator of the Universe by which to discover and measure so much of the Universe. And it is well suited to communicating this new information over the great distances of the strange environment of

space we probe, deeper and deeper. We know already how to use it—how to control it, how to put it to work so that we enjoy its wonderful advantages of precision and power, its performance virtually at the speed of light.

How do you put it to *best* use? Start close to home: at Earth itself, and the Sun which has so much control over our Earth. For there is a close relationship between Earth and Sun, one which needs more investigating. This is an investigation that can be accomplished by use of electromagnetic energy. Indeed this, in large part, will be an investigation *of* electromagnetic energy—energy from the Sun, energy which so strongly affects Earth and life upon it.

2

Space, Earth's Cradle

Sun, Earth, and Electromagnetic Energy

It is the Sun's electromagnetic radiations—sunlight—which provide energy that energizes the molecules of our air, causing some areas of air to expand and so to rise, other molecules of air to be moved in to take their place. This movement of air, called “wind,” brings with it the variations in our weather and therefore in our food supply and in our well-being. Climate results in good part from the angle at which the Sun's rays strike an area of Earth, affecting the economic life of that part of the world—a wheat-heavy Kansas, or a frozen Arctic, or an arid Sahara. Often, streams of radiation pour out into space from the Sun's surface as it boils—and then radio communications on Earth are blacked out, to the inconvenience of civilians, the consternation

of military men, and the danger to astronauts. But if we learn more about these forces, perhaps we can learn how to put them to good use instead.

So apparent is the bond between Sun and Earth, it is only reasonable to speculate whether Earth—and the other planets, too—came originally from the Sun. One of several different theories suggests that massive tongues of hot gases were torn free from the Sun, by attraction, when long ago another great star passed too close; and that these tongues eventually cooled, solidified and at last became the spinning planets, rotating captive around their parent Sun.

These hot gases of the Sun come about from the burning of hydrogen atoms, the chief substance of the Sun. Because our Sun is comparatively young, it is still well-supplied with these hydrogen atoms, still hot. These burning hydrogen atoms release and radiate electromagnetic energy. These irradiate our vegetation, and sustain it. We eat that vegetation, and so do the animals we eat. And so we absorb the Sun's energy, our physical life's energy, and we too are sustained. Small wonder that many of the ancients worshipped the Sun!

Of course, this establishes nothing about Earth's origin for it does not *prove* that Earth came from the Sun. But it does show clearly how much man is physically a part of his environment. How much he may also belong not only to Earth or to the Solar System but to his Universe, too, is part of his great quest in space.

Electromagnetic Energy and Extraterrestrial Life

Part of man's quest also is his search for other forms of life in his Universe. What are those areas of Mars' surface which in one season show green, and then brown in the next season? Are they evidence of life on that distant planet? For that matter, how do we perceive these colors? Again, through electromagnetic energy from the Sun. Bright sunlight is made up of these pulses of energy. So fast is this pulsing, so high its rate—so much higher than, say, the rate for radio waves of this same kind of electromagnetic energy—that those pulses from the Sun become visible as "light," the intense light from the intense heat of the Sun. Where there is less heat there is less energy. The vibrations are not quite so fast. The brightness loses a little of its intensity. The slower vibrations, though still visible, appear as a darker color: green, perhaps. Or, where there is still less heat, and a still lower rate of pulsing, the color becomes a still deeper one, perhaps a dull red.

The energy of the Sun's electromagnetic radiations is energy which reflects from Mars' surface (although some does originate there, too), bringing these colors of green and brown—these different rates of pulsations—as rays that are gathered by a telescope's or an eye's lens. More colors become visible when a prism intercepts this light and separates it into the colors which comprise it, for these rays may be a mixture of colors and not just

one alone. These different colors tell of the temperature with which each is associated. And so, colors scattered by a prism which is intercepting light from Mars tell of temperatures on that distant world.

Unfortunately, carbon dioxide in Earth's atmosphere absorbs one of the colors—infrared. Infrared is in the invisible part of the spectrum, invisible because the rates of pulsation which produce it are too slow for the human eye to perceive. If we go above Earth's atmosphere, above the carbon dioxide in it, our instruments could detect this infrared part of the spectrum as it comes to us in the light from distant worlds. That light would show if—or how much—carbon dioxide is present in another planet's atmosphere. Why look? Because it may mean life is there. Carbon dioxide is produced by plants. Bacteria produce it, too. And these are indeed life forms touched, no less than is man, with that magic spark.

Yet the presence of carbon dioxide still is not *proof* of the existence of life on another planet.

How much better it would be if an examining instrument were not so far away from the planet under study, not held here on Earth or just above Earth's atmosphere, but instead were right on that other planet's surface? There it could sample, examine, and report what it finds: larger life forms, plants or organisms; or, perhaps, the smaller microorganisms. Again electromagnetic energy would be the helper in this detection and reporting. One

Electronics, Key to Exploring Space

such life-seeking device uses a nutrient broth. Into this is wound a sticky string, bringing samples of whatever adheres to it—perhaps bacterial forms. The string drags across a stretch of unfamiliar other-world soil, the planet on which the device was soft-landed, unattended. In the broth is a radioisotope, Carbon 14. If an organism enters this nutrient broth, and grows and reproduces, the Carbon 14 evolves in the form of carbon dioxide. An electronic counter in the device monitors this activity. The device's radio broadcasts it to Earth. The data, when received, probably will go into a computer to be analyzed and formed into information—information which a man will then use.

Discovering and reporting life forms by electromagnetic energy can be done also by powerful television cameras. A kind of microscope is required for use with the TV camera in order to see organisms as small as bacteria, some one ten-thousandths of an inch. But what the microscope or the unaided TV examines on that other planet's surface can be telecast to Earth. There a man observes this information, and uses it.

Man in the Search

Satisfying though this is, it nevertheless leaves man who uses the product of the search, still remote from the scene. Nothing quite substitutes for a man *being* there.

But the surfaces of other planets, even of our own

Solar System, are so wildly hostile it is unlikely that a man can survive on more than one or *very* possibly two. Shall he, then, go? Under such terrible conditions, does he belong there?

One response—however brash it may sound—is, “If he can survive there, he belongs there.” And with enough knowledge of what to prepare for, and how to prepare for it, he *can* survive there.

The first step, then, is to secure that knowledge. And the best tool to use is electromagnetic energy.

Men have orbited Earth already. Enough knowledge of space conditions within one area of orbit has been gathered—principally via the use of electromagnetic energy—sufficiently accurately, and proven carefully, and applied properly, to permit men to accomplish their mission of orbit and return alive and safe. But the distance from Earth of these orbits has been only 150 miles or so. The distances which men plan to traverse in space are in the hundreds of thousands of miles, later in the millions of miles. What are the conditions there and en route against which he needs protection, and how shall that protection be provided? How different will these conditions be (if indeed different) from conditions of the one part of space he already knows?

To safely transport and maintain a man so that he can do work on another world requires knowledge that has been gleaned from a wide range of information and then has been tested, checked and proven accurate. What,

for example, are the physical conditions en route to and then at his destination? How would each of these affect him and his vehicle and its components? What are the effects of those great forces and high temperatures which result from his vehicle's tremendous speeds? How can you maintain communication with him, not only for your information but also for his safety?

To safely transport a man to another world takes other kinds of information, too. What are the physical conditions in, first, that band of atmosphere surrounding Earth through which he passes, outward bound? And, even more difficult to answer, what are the conditions in the quarter-million miles between our familiar envelope of atmosphere and the unseen boundary marked by the Moon's orbit of Earth? What indeed are the conditions even beyond that? What do they consist of? Are they dangerous to man or spacecraft? Secondly, how *much* are they—what is their quantity, their density, their strength? And without a third piece of information, the first two pale: *where* are these conditions? "In space" is not enough; *where* in space? Routes for safe travel will have to avoid harmful areas or harmful times. Instruments must be able to detect these conditions of space, identify them, and then count them or measure them—and in a way which locates *where* these conditions are and *when* they exist or disappear.

Does it appear that conditions of space and space travel are necessarily hostile to man? Perhaps they are.

But perhaps also, in this gathering of information preparatory to transporting man to another world, a great assist may come to light. Perhaps some of these conditions will be found useful to the effort rather than detrimental to it. Space itself, for example, was considered an obstacle to space flight: it cannot support the weight of an airplane or even of a balloon. But, in reality, space furnishes a fine medium for travel. It offers no resistance to a vehicle which accordingly can coast through it at enormous speeds, with hardly more expenditure of fuel than is required for the initial burst of power.

3

Exploring Other Worlds

If indeed a man is safely transported through space to work on another world, the first one of those worlds very probably will be the Moon. More reason than proximity directs him there. Very likely the Moon has a better preserved record of Earth's earliest history than is available on Earth itself. Rain and wind have long since weathered away useful clues from Earth's surface. But the Moon has virtually no atmosphere—and so, no weather. If its surface has been changed over the years, not weather has changed it but bombardment by meteorites or by interplanetary dust attracted by the Moon's weak gravity. For billions of years, this dust on the Moon's surface has been accumulating. Within it may rest forms of very early life, still preserved. Below the quiet dust, deep within the Moon's inner structure,

may lie even earlier clues—clues we seek to the formation of our Solar System, of our own Earth.

Exploring the Moon

Before a man is there to probe for this information, unmanned rockets bearing information-seeking instruments probe instead. Their mission? To learn what conditions exist on the Moon for which man must prepare himself to survive and work there. Their method of operation? Electromagnetic energy—that accurate, powerful tool. The earliest of these probes only fly by the Moon; later ones orbit it. Radar maps the moon's surface and infrared spectrometers map its rock structure; still other instruments refine the first quick set of information which the fly-by secured. Still later, more unmanned probes roar up from Earth to intercept the Moon. These land on the Moon and there detect, measure, report and record temperatures, atmospheric pressure, composition of the dust and soil beneath the dust, radioactivity on the surface and above it. Electromagnetic energy communicates this intelligence back to Earth—by television, by radio, or by recording tape stored within a returning vehicle.

These instruments are designed to report still more particularized information for man's arrival soon to follow: Is there radioactivity—above and on the surface—in the dust that comes from space unfiltered by any

Moon atmosphere? Is it in quantities lethal to man? What, precisely, is the Moon's atmosphere? How strong, then, and of what shall the astronauts' space suits for use there be made? Is the Moon's surface really of dust? And if it is, what is its composition? Can a spaceship land on it? And take off again from it? Can a robot vehicle negotiate it—and should the vehicle be tracked like a tank, or wheeled, or should it be built to “walk” like a stiff-legged man? Is there only powdery dust, or are there also blocks of rock? Many? How large? Can these halt a vehicle or wreck a spaceship?

Finally, when man walks the Moon and lives in the bases he builds there, how and of what should he construct these for his best protection against so fierce an environment? If indeed the surface is dust, perhaps this could be used in construction: it would provide good insulation against the 240° F. heat of the lunar day. Or if under this dust there is a kind of porous rock, then deep caves for these bases could be drilled—or blasted—to provide protection from meteorites and from the radiation that might be there too. One plan is to prepare a cave for men *before* they arrive on the Moon. Choose a desirable area for it, then send a robot vehicle to land there. Landed, the vehicle burrows below the surface, then sets a charge of explosives. These blast a cavity which the men finish off when they arrive, protection from meteorites and radiation already provided for them.

Clues to Earth's Beginning

Much deeper below the Moon's surface than these shallow cavities are its internal temperatures yet to be measured, yet to be radioed to Earth. Here may be still another clue to those earliest of days. These temperatures may betray the presence and even something of the quantity of radioactive elements. And these, and their history, could tell about how Earth and Moon were related in those days of our world's beginnings. Did the Moon come from the Earth; or was it once at a *greater* distance than now, and brought closer by Earth's gravity; or did Earth and Moon come into existence at the same time? The Moon is slowly moving away from Earth; measurements long ago have shown that. How long ago then was the Moon only one-tenth its present distance? The pull it must have exerted at that time on Earth's primitive oceans would have raised tides as high as a mile. Small wonder, if this did occur, that so little of Earth's early history remains on its surface. Little doubt, too, that the quiet Moon, which doubtlessly shared that history with Earth, is the place to find it intact or almost so.

Exploring Elsewhere

Earth's early history may have been shared, too, by the other planets of our Solar System. Here are still

Electronics, Key to Exploring Space

other places to explore. But the environments of these are almost impossibly hostile to man—except perhaps for Mars, Earth's neighbor. Nevertheless, they hold information we want. If man cannot survive there to explore in person, he will explore them much as he conducts any other space exploration: via unmanned probes and then via landed, instrumented vehicles guided and controlled by men on Earth or, by then, on the Moon. Still later, manned observatories will orbit some of these planets, crews of their scientist-astronauts observing at closer range and launching unmanned probes which land on the planet and radio their reports back to the mother spaceship circling above.

The origins even of the distant stars—of which our Sun is one—and of the galaxies to which they belong may be revealed through this search. We can see one billion trillion of these stars through our most powerful telescope whose range is some four billion light years. But in this scanning, this search, Earth's atmosphere filters out electromagnetic pulses of energy whose rate is in the ultraviolet range. And this, unfortunately, is the range for emission from *hot* stars. These are the few "young" stars which evolve quickly and thus display so much more information during the period of their observation. But with the ultraviolet part of the spectrum denied to observers on Earth, information which would accompany it also is denied to them.

What to do? Place observatories *above* the atmos-

phere. Unmanned balloons, specially designed to rise above nine-tenths of that atmosphere, already have carried instruments aloft. Rockets, too, have made their quick runs, for shorter periods but to greater heights. Orbiting astronomical observatories, unmanned but finely instrumented and controlled, will soon respond to radioed commands from men on Earth, in turn radioing to them the information they demand from them. And then will come the day when men themselves will be out there in their own life-supporting orbiting observatory, directing the astronomical instruments and supplementing the observations of these with observations of their own.

In all these explorations, electromagnetic energy plays a key role. And it will continue to be just as important in all future experiments in space.

What's in Space?

Many conditions in space are yet to be investigated—conditions characterized by great energies or by high speeds or by irregularity of occurrence. Or by quantities so few and energies so low that their presence or strengths are still more difficult to detect—yet these, too, should be learned. So wide a range of conditions, and varying so widely in their characteristics, demands a means of experiment that only the use of electromagnetic energy can accomplish. How to plan these experiments requires, first, some idea of what generally these conditions are and where they are to be found.

And where does that start?

Growing out of our present information and knowledge are guideposts to new experiments. These new investigations are to be made deeper in space where more information is to be acquired. More knowledge about

cosmic radiations is needed, for one thing. How shall we detect and report their presence and quantity and strength in this newer area of exploration farther out in space? Ultraviolet rays are another subject for these deep-space experiments. Tiny fragments of meteors are a subject, too, their small size belying their destructiveness through the tremendous speeds at which they travel and strike any object in their path—an object as, say, a space-suited man, or his spaceship, or the solar paddles which power its electronic equipment. Oxygen; atmospheric pressure; magnetic fields; areas of electrically charged particles which may disrupt a radio link of communication or command between Earth and spacecraft—all need to be discovered and measured still deeper in space. And how do these conditions affect the vehicle and its many sensitive instruments upon which the astronauts' survival depends? And how to detect the presence of other potentially harmful conditions, or the absence of necessary ones?

Stormy Seas in Space

Many of these conditions in this area of deeper space that need to be explored more fully are, as their names indicate, related to our Sun: cosmic rays and gamma rays, plasma, solar winds and solar flares; radiation belts, magnetic fields, electric force fields, meteorites. And the Sun, our chief energy source, also has considerable effect

upon those clouds of energetic particles which comprise the interplanetary medium. In each cubic inch of this medium there seem to be some one hundred comparatively slow-moving electrons and protons. There also are some cosmic rays of high energy, perhaps one per cubic yard. This is the relatively calm medium through which manned flights to the Moon will pass, sailing smoothly if there is no solar flare.

But when there is a solar flare, for about an hour the Sun extends toward Earth a plasma tongue of charged particles at some 1,000 miles per second. It envelops Earth. The once calm channel of flight to the Moon now becomes a most dangerous and "stormy" sea—a storm of radiation. Space-sailors, like sea-sailors, should either avoid storms or be equipped to survive them. Here in space, survival equipment is a lead chamber within the spaceship—sometimes called a "storm cellar." Inside it during the storm, the men are shielded from the hazardous effects of the storm's protons shooting out from the Sun, from cosmic radiation, and from electrons trapped in Earth's radiation belts.

Survival "equipment" of quite another kind is alertness to this danger by the astronauts in flight and by their supporting crews on Earth who have monitored, for weeks beforehand, this threat of solar activity which they continue to watch for, ready to warn the astronauts. But we need still more knowledge of these storms. How do these solar flares start? One scientific guess is

that the Sun's peculiar rotation causes this turbulence. The Sun's north and south poles require thirty days for one rotation, but its equator takes only twenty-seven.

And as for the general cosmic rays which speed into our Solar System from who-knows-where, even less is known. Probably they come from somewhere within our galaxy, possibly from beyond. As they pass through magnetic fields in space, these whip their speeds higher and higher. Their power to penetrate anything—space-ship, human bone—grows with each such acceleration. How difficult will *these* be to shield against? And how dangerous are they? Their few numbers misrepresent their considerable effects. The great Van Allen radiation belts, extending some 25,000 miles from Earth, threaten those who would pass through them; yet they contain only about a pound—perhaps a handful—of material.

The Solar Wind of Space

From the Sun's surface, the solar wind streams out, a constant flow of particles. During the eclipse of the Sun it becomes visible as the corona. The movement of this flow produces a magnetic field and probably also an electric field, forming the plasma that is called the solar wind. So closely does this resemble the interplanetary medium (although the latter is far less dense) that some scientists speculate that the interplanetary

medium is merely an extension of the Sun's atmosphere. This is the "empty" space between Earth and Sun, space as we know it. Magnetic fields are contained in it, and also cosmic dust. High energy cosmic rays penetrate it. Permeating it is plasma, that mixture of electrons and nuclei of atoms, ionized. Through this man plans to travel, has indeed already ventured his first few steps.

Through this also move the Sun's radiation and particles on their way to Earth. As they do, they affect it, causing another kind of weather, the solar weather of space, an electrical magnetic weather. Earth's weather is probably influenced by these conditions. But even more certain is the belief that these particles are responsible for that layer in our atmosphere, the ionosphere, against which we bounce our radio signals for around-the-world radio communications. (Unfortunately, these particles also are responsible at times for disrupting that layer.) Still more fundamental than our communications and even our weather is the knowledge that these infinitesimal electrons and protons are, despite their inconsequential size, the stuff of what we and our Universe are made. The energies of several kinds of these are so great that only a comparative few could destroy us if it were not for our atmosphere's shielding. Probably they also would destroy voyagers through space unless routes are carefully chosen in advance. To know where and when to find these danger areas means to have learned more about them.

5

Steps into Space

Experiment in space, now by unattended instruments, some day will be by men operating or monitoring those instruments *there*. Study on Earth has long been a man-instrument team, like the astronomer and his telescope. The scientist-astronaut, aiding his information-seeking electronic instruments, is really a kind of follow-on to the astronomer whose instruments show him only what has not been filtered out by Earth's atmosphere.

Nor are spacecraft that land safely on another planet and telescope anchored to Earth so unlike. Both are, and are equipped with, instruments for seeking out information about physical conditions in areas and on places beyond our Earth. Both use electromagnetic energy to gather their preliminary information, those masses of raw data not yet usable knowledge.

The Spectroscope

The spectroscope, another of the astronomer's instruments, also uses electromagnetic energy. It breaks up a beam of light into the colors which compose it. It does this by a prism or by another device called a grating. Waves of electromagnetic energy pulsing fast enough to be seen produce these colors. The colors at the lower, or red, end of the spectrum are produced by the slower-pulsing waves of electromagnetic energy; those at the higher or violet end, by the faster-pulsing waves.

Radio waves, although they are electromagnetic energy too, are slow by comparison, even those which pulse at millions of times per second. The faster the rate of pulsing, the shorter is the length of the wave. Wave length is measured in meters. "Short wave" radio wavelengths, produced by the faster-pulsing radio waves, are hundredths or even thousandths of a meter in length. But wavelengths of light are in millionths of a meter (microns), thousandths of a micron (millimicron), and tenths of a millimicron (Angstrom, or A). Even there the spectrum of electromagnetic pulsing and wavelengths does not end. Beyond light's ranges are the invisible rays going as high, according to our present knowledge, as the cosmic rays whose frequency of pulsing is 10,000,000,000,000 (ten trillion) cycles per second.

A great deal of information about space is available

right here on Earth by use of this spectrum of electromagnetic energy. When the spectroscope's prism or grating breaks up the light coming from other worlds, it is in the colors or wavelengths of energy which compose that light and which relate to the substance emitting it. The spectroscope has even found that the Sun, like the Earth, is a magnet and that its spots also are magnets. It has measured the Sun's temperature, its speed of rotation, and its speed as it moves among the stars of our galaxy. By studying these electromagnetic waves of energy—their quantities and directions and movements and intensities and their composition—astrophysicists learned that the Sun has an atmosphere. They also find that this atmosphere of the Sun has some sixty-six elements we know on Earth, simply by comparing the colors broken out of sunlight with the color spectrum of substances belonging to Earth. When the Sun's corona appears during eclipse, spectroscopes study that visible ring and find its radiations are what highly electrified atoms of iron and nickel and calcium would emit. Spectroscopy also shows that these and other familiar chemical elements are distributed uniformly in the Universe.

Levels of Exploration

Yet the spectroscope, like the telescope, is blind to other areas of information we need in order to ascend into space. Much of that information concerns experi-

menting and counting and sampling—radiation belts, effects of the Sun's energy, ionization, particles, magnetic fields. Even our own atmosphere is a subject of study.

The ascent from Earth into space is step by step, from one level to still more distant levels. Each level has its own requirements for study and the means to conduct it. Study of our atmosphere has been carried out by instruments aboard balloons and, later, aboard airplanes when these could be made to reach great heights. Specially designed balloons then ascended far higher than any airplane's ceiling, almost to the very edge of space. Some of the experiments they carried were alive, now that it seemed men would some day reach—and surpass—those heights. Are these mice, carried aboard, becoming badly dosed with harmful radiation—as would an unprotected man in space?

Then the balloons' mark was topped many times over by rockets when these became readied for space research. More than only achieving still greater altitude, their quick ascent and descent offered a cross-section of all levels of atmosphere and above, within the short time of only a few minutes. Some experiments could find excellent use for that facility: How well do monkeys stand a rocket flight, before a man makes the same kind of flight?

Farther out, beyond these ranges, is the next level to be explored, the area of orbiting Earth satellites. Graz-

ing Earth's atmosphere as close as one hundred miles, sometimes extending as far out in their orbits as several thousand miles, these instrument-carriers look up, and look out. Some look down, too, viewing Earth's atmosphere, and particularly its ionosphere, with a completely new perspective. For by now the rocket's guidance and control systems have become advanced and reliable enough to follow instructions and deliver that payload of intelligence-seekers—the satellite with its instruments—where it is wanted. No other vehicle matches the rocket for this unique job; none has the necessary enormous power and independence from the atmosphere.

In the lofting and orbiting of a satellite, the rocket precisely follows detailed instructions. Although these might be commanded by radio, most often they are stored within its electronic "brain," its computer. Either technique uses that precision tool, electromagnetic energy. Its instructions send the rocket roaring up to a designated height, perhaps three hundred miles. By the time it gets there, the rocket's great power has pushed its speed to some seventeen or eighteen thousand miles per hour. Obeying its instructions, the rocket levels off and then separates from its payload, the satellite. At this speed, the satellite is too slow to pull free from Earth's gravity. The satellite continues its flight at that great speed, neither going up nor down—just around and around the Earth, a prisoner like the Moon.

The probe that penetrates deep into space, to the

Moon or past Venus or around Mars, requires a still greater speed. Here is no satellite, no orbit. Instead, the rocket's instructions send it streaking away from Earth at some 24,500 miles per hour. This is fast enough to overcome the pull of Earth's gravity. Free of Earth it follows the flight path calculated long in advance and programmed into its computer.

Perhaps these instructions direct the rocket and its payload of instruments to fly by a planet. Or perhaps these send it close enough so that it becomes a prisoner of that planet's gravity, circling and reporting as the Earth's satellites do. Perhaps the instructions guide it directly to a landing on that body, a "hard" landing which smashes its instruments—but not before they have radioed all they perceived up to the moment of crash. Or perhaps these instructions are still more detailed and the guidance and control systems still more complex, so that the payload is "soft" landed and its instruments continue their perceiving and reporting *after* the landing as well.

And some day, not too distant perhaps, the rocket's soft-landing is followed by the unloading of another and still more versatile, self-directing instrument—a man.

But before a man is landed on the Moon, or later, on another planet, there are still further levels of space to be explored. Cislunar space is one—that area between Earth's atmosphere and the Moon's orbiting path. Earth

satellites with very eccentric orbits penetrate deeply into this soundless sea, seeking information to prepare the way for man's voyage through it en route to the Moon. Rockets, too, probe still deeper, seeking more of that information. Long before a spaceship is built and its voyage begun, those who build the ship and who chart its course and who establish its communications link with Earth must know that the physical conditions of that area of space will not deteriorate the skin of the spaceship, will not spoil or misdirect the many delicate electronic instruments which direct it safely to its destination.

One level of research remains in this information-seeking before man lands on the Moon. That level is the Moon itself. Before man touches its surface, before he can be assured of a safe landing, his spaceship's builders and its flight planners must know precisely what conditions surround the Moon: atmosphere and gravity field for computing the spaceship's entry and then its landing maneuvers; magnetic fields for determining their effects upon the craft's electronic guidance and communications gear; the Moon's surface itself for selecting landing areas free from risk of destruction in landing on the steep side of a lunar mountain or deep in a lunar crevasse—with the nearest help a world away.

And then there is the additional information needed for the safety of the man while *on* the Moon.

The Ultimate Instrument

But the Moon is not a final objective; it is only a springboard to still more distant space exploration. The questions that were asked of cislunar space now must be asked of interplanetary space, the space between planets, the next level of exploration. Then follows the unmanned instrumented orbiting of the planet to be explored, and then the unmanned instrumented landing. At last the time comes when a man emerges from a spacecraft and steps out on to that other world.

He is there to work. His job: to function as a scientific instrument where there may not be just the right instrument to perceive and sense the unexpected conditions. A man may well replace a whole battery of instruments and, despite the mass of information he thereby perceives, he will know what is important in it and what need not occupy his attention further. For evaluating or deciding, man is the ultimate instrument. No computer could have been programmed to meet such unexpected conditions or to treat with so many.

6

Man and Other Space Instruments

The information sought by the instruments of satellites and probes is scientific or biological or engineering. A rocket flight with a monkey as passenger, before a man was risked to the still unproven vehicle, may well have carried all three types of these instruments. Engineering instruments in the rocket frame and shell and in the controls reported conditions while these were subjected to the strains and stresses of lift-off and re-entry. Scientific instruments reported amounts and types of radiation as Earth's atmosphere thinned out into open, unshielding space. Biological instruments, fastened to a monkey, reported the animal's heartbeat and respiration and consciousness and evidences of comfort or discomfort during lift-off, weightlessness, and the buffeting and heat of re-entry.

These information-seeking instruments, whether en-

gineering or scientific or biological, are called *sensors* or end-instruments. In a way, man himself embodies a series of such instruments. His fingers, for example, are a kind of end-instrument: they are designed to sense, by touch, and to relay that sensation to his information center, his brain.

Each sensor is designed to be sensitive to the physical condition it is to seek and measure or count. When it encounters an indication of that condition, it then "senses" it. It changes that indication into electricity. And it does so in a form which permits radioing it or storing it on magnetic tape for a later reading.

Scientific Instruments

Scientific information sensors report on the kinds and quantities of the elements of the Universe. They measure the areas and strengths of magnetic fields close to Earth or to the other planets of our Solar System or close to the Sun and perhaps, some day, close to other systems of our galaxy. They tell about solar radiation and the little known cosmic rays arriving from deepest space. They measure "secondary radiations" *within* the spacecraft when cosmic rays produce these by interacting with the spacecraft's material and equipment.

A typical payload of scientific instruments is in an early Mariner spacecraft. This craft's mission is the flight past the planet Venus. A microwave radiometer

measures the temperature of the planet's surface and seeks detailed information about its atmosphere. The infrared radiometer is sensitive to moisture in the air; it learns and reports any fine structure there may be in the planet's cloud layer. A magnetometer measures changes in magnetic fields, both en route in interplanetary space and then in the vicinity of the planet. An ion chamber and particle flux detector identifies the distribution of charged particles. A cosmic dust detector measures not only the density of cosmic dust but also the direction of its movement. And the solar plasma spectrometer measures the intensity of low energy protons coming from the Sun.

The TV camera certainly can be called a scientific instrument when it searches for extraterrestrial life. On another world, mounted near vegetation growing in that grotesque soil, it is designed to view these growths and telecast to Earth what it perceives. Flying by another planet, a vehicle carrying TV camera and transmitter can view and report to Earth what *it* perceives. This TV camera, too, is a scientific instrument.

Carried above Earth's atmosphere, the once Earth-bound spectrograph seeks new scientific information. (The spectrograph is virtually a spectroscope, but with a camera in place of an observer's eyepiece.) It scans the surface of Mars, among other neighboring bodies in space, for evidences of extraterrestrial life. Infrared radiation is emitted by any object, even by gases, whose

temperature is above absolute zero. Each has its own infrared "signature" of lines on the spectrograph. Scanning this most life-likely planet, Mars, the spectrograph seeks the lines that are characteristic of life forms.

It is questionable whether a man can contribute much to these instruments while in space flight with them. But certainly he will supplement them while he is with them on the surface of another world. As he works with them, he can say much more than, "I understand." He can and will say—and this makes him unique among instruments and computers, and is the chief reason for his presence on that other world—"I can fill in the gaps in this information with conjecture that's probably correct." This is what he says on Earth after he has assembled the results of an unmanned instrumented exploration. How much better, then, if he can be where these data are collected.

On Earth or in space or on another world, he is a part in almost all these systems of instruments. He is able to evaluate what they are reporting, to decide what to do about it, and then to do it. In this respect he does indeed "close the loop" of scientific instruments and complete the information system they comprise.

Biological Instruments—Biosensors

Man himself is a system, in a sense; or, more properly, a series of systems. His body is his personal vehicle,

analogous to the rocket; its payload, his brain—the computer—to which are connected his sensors: eyes, ears, touch, and sensations. Early in space flight it was necessary to instrument *him* in order to learn how well his body and its vital functions were reacting to the strains and new environment of space and flight in it. These instruments are called *biosensors*. They were fastened on and in him to sense and measure heartbeat and respiration and temperature, and then to report by radio to Earth below. This is still done and probably will continue to be done at each new level of space flight.

On Earth, men study a panel of instruments in front of them which shows what the instruments in the spaceship are radioing to them. From the biosensors, they know more about the astronaut's condition than he does. If they see that he is beginning to malfunction, and is in danger, they can override his control of the spaceship and bring it automatically to Earth, safely. Thus far, however, their instruments report that he is well. The tone of his voice has confirmed that during radio conversation.

"Friendship Seven, this is Zanzibar Surgeon . . . Your electrocardiogram is excellent . . . Everything on the dials indicates excellent aeromedical status. Over." *

"Roger, Friendship Seven . . ."

* Quoted material is from the verbatim transcription of the MA-6 flight communications as contained in "Results of the First United States Manned Orbital Space Flight, February 20, 1962." NASA. John H. Glenn, Jr., Astronaut.

But there is more than physical condition to learn about in this strange environment with its unearthly zero-gravity state of weightlessness for those who venture into it. Here are *sensations* to be reported. Instruments talking to instruments give way to man talking to man.

"This is Friendship Seven. The head movements caused no sensations, whatsoever. Feel fine . . . I have no problem reaching for knobs and have adjusted to zero-g very easily, much easier than I really thought I would . . ."

"Friendship Seven, this is Zanzibar Surgeon . . . received your report indicating good reach accuracy . . ."

Engineering Instruments

Engineering instruments report on the rocket's shell and controls and even its fuel sloshing, which affects the vehicle's balance and flight path. But after the booster rocket has separated from the manned capsule there still is information to be reported about the craft's controls, information to be reported by the astronaut himself.

". . . this is Friendship Seven. Are you ready to copy panel rundown? Over."

"Roger, Friendship Seven. This is Zanzibar CapCom. Proceed."

"Ah, Roger, Zanzibar CapCom. Friendship Seven. All fuses remain same as previously reported; have not

changed any of them . . . Auto Retrojettison is off . . . Retro Delay is normal. The sequence panel is normal. Landing bag is off. Fuel is 90-98 (per cent) . . . Over.”

Still another system supports the life of the astronaut within the capsule: oxygen, pressure, temperature, and so on.

“ . . . Seven, Cap is Go; we’re standing by for you.”

“Roger. Cap is Go and I am Go. Capsule is in good shape. Fuel 103-102 (per cent), oxygen 78-100 (per cent), cabin pressure holding steady at 5.8, amps is 26. All systems are Go.”

“Roger . . .”

And then there is information an instrument just cannot express:

“The capsule is turning around . . . Oh, that view is tremendous!”

Theories into Space Projects

How does a space experiment, a space project, come into being? Who proposes it? Who decides which experiment is to be built and carried out?

Researchers ask the questions about space which can be answered by instruments via electromagnetic energy. And they also use the information which these instruments and their electromagnetic energy will report. These researchers are in universities, in industry and in government. Their questions may have resulted from something they read in current scientific literature. Or perhaps it was something they heard or were discussing with other researchers, in their associations, which started the thoughts that led to the specific question. Theoreticians speculate—realistically—about the composition of space and the Moon and planets, often using quantum physics to develop their theories. But other

good theories come also from the most pragmatic of researchers, too.

Many of the researchers are in other countries. In this country, the National Aeronautics and Space Administration is responsible for our search as a nation for information in space. NASA cooperates with those researchers of other countries who do not have the powerful rockets, the sophisticated satellites and probes, the ground launch complexes and the sensitive tracking stations which are needed to put instruments into space and then to "read" them there for answers to those questions they ask.

NASA asks its own questions, too. Men in its Space Science Division, whose backgrounds include experience with rockets and satellites, are aware of where there is a gap in knowledge. They can and do propose satellite science experiments.

Selecting the Experiment

There are more questions asked and experiments proposed than there are satellites and probes to carry that many instruments. Competition therefore is keen, and selection of experiments is careful. It begins with the proposed experiment and its instrument being described in writing: what the instrument is, its limits or capacities, its mission.

Each write-up is studied and its experiment evaluated

by a selected group of men who are experienced in the field relating to that experiment and its instrument. In the case of NASA's Goddard Projects, these men are at the Goddard Space Flight Center near Washington, D.C. Even if they approve it, it must also be approved by Life Sciences or Space Science or other office in NASA to which that experiment pertains.

There the experiment is examined still more closely. Does it require a satellite or a probe? Is it to measure, or count, or both? Where in space and time should *this* experiment be placed? (The preliminary plan grows to book size.) Answers to these questions reveal the cost of building the instrument and delivering it in space for the experiment. The money for that comes from headquarters of NASA.

The Instrument's Delivery Vehicle

If the plan is approved, the first job is finding the right men and the right vehicle for the work. First, what kind of rocket vehicle and its ground support are required? The points in time and space for the experiment dictate the answer. Next, does such a rocket exist? What is its availability? What is its cost?

Then they consider the spacecraft, perhaps a satellite. For the present, this is just the empty container. What are the physical and structural characteristics of available spacecraft, their ability to withstand strains of

rocket flight and effects of space temperatures and pressures and other space conditions? Only after determining this do they begin to consider the container's capacity, and then it is just in terms of general size and weight. They list, too, any other restrictions relating to that container, a spacecraft minus its payload of instruments.

The Thermal Design Problem is stated: just where to coat the spacecraft's skin with light paint, and where with dark paint. These will balance the spacecraft's taking in and putting out of heat absorbed by the Sun or generated by some of its instruments. In space there is no air to carry off excess heat which would damage delicate electronic gear aboard the craft.

Having come this far, sometimes they are obliged to conclude that the spacecraft needed for these particular experiments would take too long to build—perhaps two years. By then, those planned experiments will have become obsolete. Instead of going back to the beginning at this point, NASA saves time and looks ahead by attempting to estimate the types of experiments which will be of most value in the future. Then NASA determines what these experiments' weight and power and stabilization requirements will be. And then they begin building a spacecraft for these experiments—having, now, a rather specific set of requirements and limitations to work from.

Still saving time, NASA now invites the experiments

it attempted to anticipate. There is the usual competition among experimenters. But for those whose experiments are chosen, there will be few problems in designing the construction of these. The spacecraft is now built (or almost so), and so space and weight and power supply for the experiments also are established. Now the experimenters will not have to make last-minute changes in the construction of their experiments to conform with last-minute changes in the construction of the spacecraft. The spacecraft is set; there are no changes.

Controlling the Instruments on Board

The next consideration is the information which the instruments are to provide. Some instruments are to count "now" but not "then." Some are to measure "here" but not "there." And this means furnishing the spacecraft with electrical and electro-mechanical and mechanical equipment to accomplish this. The more there are of these equipments, the less weight and space is left aboard the spacecraft for the experiments themselves.

Even the simple problem of when to read each one of the instruments turns out to be, after all, not quite so simple. Not all instruments can always be read at the same time. If they are to be read in sequence, one way of doing that is by "commutating." This does not necessarily mean looking at these instruments in a set order

and for equal periods of time. Some experiments require more frequent reading than others: a spacecraft's attitude, for example, has to be checked frequently because this can change quickly. Changes in temperature, on the other hand, can be expected to be quite gradual and so their readings can safely be less frequent.

Missions and Projects

Eventually, the instruments are fitted into the spacecraft. Also fitted in are equipments to supply power to operate these instruments, and those which will stabilize it in flight with the attitudes some of the experiments will require. Communications equipment and *its* power supply is designed and built and fitted into the spacecraft, too—the transmitters which will report the experiments' findings and the receiver which will pick up the commands issued from Earth to the spacecraft.

Here, too, is the computer, programmed to carry out those instructions when they are received, as well as instructions to be followed automatically as the master clock system in the spacecraft measures off the pre-calculated periods of time. And all these equipments are made compatible with each other so that electromagnetic energy used or produced by one will not interfere with the operation of its neighbor.

Instruments and systems are made compatible also for the work each has to do. They belong together in

the same spacecraft, in light of the mission all are to perform. A satellite which is to orbit Earth and gather information concerning radiation belts has a different mission than the probe which is to fly by Venus and sample its atmosphere's temperature. For each mission's work to be done in just the right way at just the right times, each step in the mission must be calculated and plotted precisely, in advance, and executed just as precisely by the spacecraft itself and by its instruments aboard. The spacecraft's computer is almost always responsible for this precise execution. Its responsibility carries through the vehicle's pre-launch, launch, flight and, if there is to be a landing, through landing and possibly even after landing.

Just as there are steps in a mission, so are missions themselves steps in a project. A project is a series of missions, each one using the knowledge gained by its predecessors to reach out still farther in space or in time or in detail for still more information.

This building upon a preceding effort in the search for new information is known as fundamental research. Directed research is for a somewhat different reason: to refine the equipment itself so that each mission's equipment works better than that of the previous mission. This directed research depends upon a *series* of efforts for its success, too. In either case, with each succeeding effort, you learn what you did *right* as well as what you did wrong, and benefit from it.

When at last a project has run its course and its missions have brought the knowledge they were sent to secure, the project itself may be followed by another project—another series of missions, under another project name, reaching out still farther in this pursuit of knowledge.

Mariner—Its Experiments and How They Work

Mariner is a project. Its early spacecraft have planetary fly-by missions. They are to learn about temperatures and atmospheres and magnetic fields of Venus and Mars. The project which follows Mariner is Voyager. This series of missions is to orbit Venus and Mars to learn more details of the broad information reported briefly by the Mariner fly-by's. Later, Voyager spacecraft will land instruments on those planets. Unattended, they will radio their findings to Earth. Still more powerful rockets than today's will be developed by that future time, so later Voyagers will undertake still more distant missions. They will fly by Mercury and Jupiter. Probably the follow-on to the Mercury and Jupiter fly-by's will be the familiar cycle: first, to

orbit the new planet, then the landing of instruments on it. And so the progression continues.

Sometimes, if you are lucky, a mission will perform so beautifully that you can save the time and expense of the next one you planned, and leapfrog to one you planned for still later. This has happened. Mariner II functioned so well on the first Venus fly-by that there just was no need for a second, similar shot. Instead, time and effort were transferred to a Mars shot which is more difficult, and to developing more sophisticated Mariner spacecraft for Venus shots that are to gather more detailed information than did the first. Saving time is important, for planets cannot be hurried through their orbits around the Sun. When they are near, you must be ready to launch your spacecraft. If you are not ready, you have to wait another nineteen months for Venus, another twenty-five for Mars.

Mariner II's Objectives

In this first successful Venus fly-by, two of the eight scientific experiments aboard were concerned only with Venus itself. One searched for water vapor in the Venusian atmosphere, the other measured the temperature of the cloud cover that forever shrouds this planet from direct view. The six other experiments also reported in the vicinity of Venus but, unlike the first two, they reported while en route, too. These six were con-

Electronics, Key to Exploring Space

cerned with magnetic fields, high energy radiation, cosmic rays, particles of still higher energy levels, cosmic dust, and solar plasma.

Other instruments aboard Mariner, although not scientific experiments, reported data back to Earth. These were engineering data: how well the spacecraft's various systems were operating, their voltages or temperatures or pressures, and so on. But when Mariner came near Venus, the engineering instruments switched out. All the spacecraft's capabilities were concentrated on the final objective of the entire effort, the scientific information.

The Microwave Radiometer

Only ten hours away from Venus, the water vapor seeker starts to work. This is a microwave radiometer. It seeks water vapor via electromagnetic energy. As its name indicates, it is a measurer (meter) of electromagnetic radiation (radio) in the wavelength range of *microwaves*. As it scans, it "nods" up and down; an electric motor drives it through an arc of 120 degrees—one third of a circle. It does not need to move from side to side. That direction of scan is taken care of by the direction of movement of the spacecraft as it sails past Venus. When it "sights" Venus, its nod is slowed to one-tenth its former speed. This is done upon instruction by one of the computer type instruments aboard. That

instrument also commands a reduction in the size of the nod: it no longer is 120 degrees, but only from edge to edge of Venus. When the radiometer's signals show that it has scanned Venus and is now looking at the edge—the limb—of the planet, the direction of its scan is reversed.

The scan is a seeking of electromagnetic energy radiated from Venus in the 13.5 millimeter wavelength. It is in this part of the electromagnetic spectrum that water vapor is detectable in atmosphere.

The radiometer's dish-shaped antenna also collects waves of energy at a different length, 19 mm. These tell if the edge of Venus is lighter than its center, or is darker. If the edge is lighter, it means that Venus' high surface temperature is due to a dense ionosphere. That condition would alter the design of communications equipment and instrumentation of future Venus shots. But if the planet's edge shows darker than its center, then the 800° temperature comes instead from its surface, and soft-landed instruments, specially designed to survive such heat, will have to substitute for astronauts.

In the measuring of these collected waves of electromagnetic energy, a question occurs. "Is it much, or is it only a little?" "Much" or "little" compared with *what*? Not, certainly, compared with what's normal for conditions in our part of space where Earth is. The norm—the reference—has to be from out there, in that part

of space where Venus is. "Much" or "little" must be compared with what should be expected out *there*.

This is another job of the microwave radiometer—to provide the reference, the local yardstick, against which to measure any 13.5 mm. and 19 mm. signals coming from Venus, and to show if these are what should be expected from out there. It does so by collecting electromagnetic energy in the 13.5 mm. and 19 mm. bands from that region of space where Venus happens to be. A special receiver does the comparing, the measuring of the Venus signals against the reference signal. The results go radioing Earthward.

The Infrared Radiometer

Attached to the antenna of the microwave receiver is a five-inch tube weighing 2.7 pounds—the infrared radiometer. If the spacecraft passes close enough to Venus, this instrument accurately measures Venus' cloud cover to confirm whether it is, as Earth-bound scientists believe, -38° F. It also answers other questions: Does such cold come altogether from the cloud tops or does it emanate from atmospheric surface? Are there any breaks in Venus' seemingly unbroken cloud cover? And if there are, how much heat escapes through them?

In its workings, this radiometer measures electromag-

netic radiations as does the microwave radiometer. However, these are not microwave but infrared: faster-pulsing, higher in the electromagnetic spectrum, above the radio range and in the optical range, almost visible to human sight. Just a shade below it, in fact—just below the “slow” pulsing red at the bottom of our visible spectrum which we often see as a rainbow.

Working together with the microwave receiver, this infrared radiometer gathers electromagnetic radiations from Venus and, for reference, from empty space also. And these too are “chopped” and fed alternately at two different wavelengths, and their results of “how much” are radioed Earthward.

The Magnetometer

All through the journey in space and at the fly-by some 36 million miles from Earth, the magnetometer measures the strength and direction of magnetic fields. It does this with simplicity itself: by a six-inch tube, with a diameter of three inches, containing three special metal tubes. These are placed vertically, horizontally and laterally—in the three axes of direction. Each tube is wound with copper wire. The presence of a magnetic field makes itself felt upon the wire; and the direction of the lines of force of that field will coincide with the windings on one of those three special metal tubes.

Unwanted electrical fields are sometimes created by

Electronics, Key to Exploring Space

the functioning of some of the electrical components aboard the spacecraft. Those fields would interfere with the functioning of the magnetometer, and so that instrument is located away from them.

The Ionization Chamber

High energy radiation in space could prove harmful to man and to his spaceship's instruments unless all were adequately protected. Measuring high energy radiation is the function of the ionization chamber, while the spacecraft traverses its long sweep through space to Venus. The chamber does its work by measuring the rate of ionization of cosmic rays.

Electrons, protons, and alpha particles, with an energy from five million electron volts to forty million electron volts penetrate the stainless steel wall of the ionization chamber only one-hundredth of an inch thick. Once inside, they are treated in a way which produces an electric pulse when an electrical charge has built up from an accumulation of these. That pulse's strength is measured and the spacecraft's radio transmits this information to Earth.

The Geiger-Mueller Tubes

There are three of these special tubes called Geiger-Mueller tubes. Their work is similar to the ionization

chamber's. Two of these tubes can be penetrated by particles, ones of still higher energy levels than those that penetrate the ionization chamber. Also, these tubes count their particles. The third Geiger-Mueller tube accomodates those particles not strong enough to penetrate the other tubes or even the more easily penetrated ionization chamber. The tubes are gas-filled and with a central wire which is electrically charged. Every time a charged particle penetrates a tube's wall and enters into the tube, it generates a current pulse. Though tiny, it is strengthened by the spacecraft's radio and transmitted over the millions of miles to Earth.

The Cosmic Dust Detector

Cosmic dust can be still another potential hazard to spacecraft. It may puncture the vehicle's skin, if it travels fast enough or is large enough or if there is a sufficient quantity of it. Any equipment or instruments or solar panels exposed outside the shell of unmanned craft also might be injured by these particles of space dust. The cosmic dust detector's function is to hear interplanetary dust striking its five-by-ten-inch sounding board. In the center of the board is a crystal microphone which picks up that sound. The sound is amplified and recorded. When the recording is played back, it tells to the skilled listener not only "how many" particles are

there, but also how hard these hit, and even something of their size.

The Solar Plasma Detector

The solar plasma detector's name tells its function, and tells, too, that it points toward the Sun. Even very low energy particles can enter this open-ended instrument, with its curving tunnel, one side of which is negatively charged, the other, positively.

The flow of these charged particles through the tunnel produces an electric current. This is measured by a highly sensitive electrometer. If the particle is not moving too fast or too slowly, it avoids both walls and continues to the tunnel's end where it is counted. Its arrival there thus implies its rate of speed: it would not have arrived there at all if it were not traveling at this known rate.

Ranger, Moon Sleuth

Ranger is the project whose principal purpose is to secure information which will open man's way to visit the Moon. Nine spacecraft are planned for this sequence of efforts. The mission of each is a carry-on of its predecessor's success. All point to the Moon.

The earliest flights in this project were fly-by missions. As in any space project, the type of information you want at the beginning of a project is usually a "broad picture" kind. Your later missions will focus closer and closer upon the details, but first you seek information seen better from a distance.

But another reason why Ranger's earliest missions were fly-by has to do with the spacecraft itself. Ranger was going to be required to maintain a fixed orientation while traveling through space: no twisting, no tumbling,

no wobbling. It takes time to engineer and build a spacecraft whose flight control systems will accomplish that. And it takes time, even before flight, to test it properly. Fly-by is simpler in its guidance and control requirements than is, say, a soft-land mission. If early in the project you can develop a reliable spacecraft for a series of fly-by missions, you benefit in several ways.

First, you simplify what otherwise would be complicated problems of guidance, internal temperatures, radio communication, and the like. Second, you standardize on a craft which then can be a sort of "bus." A whole series of missions can have its instruments fitted into this standardized, reliable craft. It is specially designed to accept these kinds of experiments because all are in the same effort, for the same project. And finally you save a great amount of money, time and effort: you don't have to custom-build a spacecraft for *each* new shot.

Rangers I and II were designed for fly-by of the Moon. They carried light scientific experiments for measuring magnetic fields, radiation, cosmic dust, and the like. They also carried one engineering experiment. But Rangers III, IV and V have the mission of *hitting* the Moon. Before they hit, however, they are designed to discharge a capsule whose retrorocket slows the capsule's descent enough to rough-land the scientific instrument. (The capsule has a nickname "Tonto," because it is the close companion of each "lone" Ranger.)

In addition, these Rangers carry television cameras. So do Rangers VI, VII, VIII and IX. Their cameras, however, take clearer, sharper pictures of the lunar landscape, and each craft carries six.

A Ranger Mission

Step by step is the means by which each Ranger carries out its mission, unmanned. Ranger IV's mission is typical. It is made up of a detailed, step-by-step series of actions performed automatically within the spacecraft after it separates from its boosters and begins its lone trip to the Moon. That trip takes some sixty hours. During this time, Ranger is to leave Earth, achieve a parking orbit, and reach escape velocity (24,500 miles per hour) at the point where its outward flight will bring it to the Moon. Free of its boosters, it relies on its own "brains" and power supply.

It uses these for the next step: to maneuver so that its sensors which relate to its attitude system, will pick up electromagnetic energy coming from Earth and from the Sun. The maneuver is a rocking forward and backward (pitch), leaning from side to side (roll), and twisting or slewing (yaw)—the three axes of direction. When these maneuvers have brought the sensors in line with the light from Earth and Sun, the sensors use that electromagnetic energy to notify the attitude system to hold the craft in that position—to "lock on."

Now Ranger is aligned so that its radio receiver antenna is in the best position to receive radio commands from Earth. These come. In response, Ranger fires its mid-course motor precisely according to the command, which itself is precise. This burst of power jockeys the spacecraft so that it is oriented into a new flight path—a collision course with the racing Moon.

Again, it locks on to Earth and Sun.

When Ranger closes to within 5,000 miles of the Moon, it carries out a pre-planned maneuver for this terminal phase of its flight: it re-orientes itself so that its television camera faces toward its target, the Moon. On approach, this camera takes and sends television pictures of the Moon's surface.

Instruments aboard Ranger study the lunar surface; its composition, its characteristics of radar reflection, and for any other information which could be used by the designers of lunar landing systems in spacecraft that are to come later in this series of Moon exploration.

At 70,000 feet above the Moon's surface, Ranger discharges a capsule equipped with a retrorocket. It plunges toward the Moon at 6,000 miles per hour until within some 1,100 feet from it. Then the retrorocket blasts. The capsule's descent at 6,000 mph. is checked to zero velocity. Another capsule separates from it and falls the remaining 1,100 feet by the pull of the Moon's gravity, which is only a sixth of Earth's. The capsule and the instrument inside it survive the fall. The instru-

ment positions itself upright on the Moon's surface. Then it goes to work, sensing tremors from moonquakes and from the impact of meteors as they strike the Moon's surface. It radios this information to Earth.

All of this is done, unmanned.

The Instruments

Ranger IV carries three scientific experiment instruments, not counting the contents of the capsule which separates from it at the lunar altitude of 70,000 feet. These are a television camera system, a gamma ray spectrometer, and a radar altimeter.

The *radar altimeter* has another function in addition to its usual job of measuring altitude by radar and thus determining the proper time for separating the capsule from the "bus" and firing its retrorockets at 1,100 feet from the Moon. It also tests the Moon's surface for radar reflectivity. To accomplish both its jobs, the altimeter sends out some 500 pulses of electromagnetic energy per second, each pulse lasting two-thousandths of a second. The radio frequency of these pulses of energy is high indeed: 9,400 million cycles per second. Precision is the hallmark of this instrument's operation; and precision it must have, to do its two-fold job successfully.

The *gamma ray spectrometer* is, as its name indicates,

a measurer of electromagnetic waves in the gamma ray part of the spectrum. It seeks this kind of information from the Moon to learn something of the composition of the rocks and dust there. It searches to learn if these are similar to Earth's. Uranium, radium, thorium and potassium have radioactive isotopes. Their radiation is in the range of gamma rays (which physically resemble high energy x-rays). If any of these rays are coming from the Moon, the gamma ray spectrometer will separate them into their characteristic and identifying components much as the solar spectrometer breaks sunlight into its components.

The gamma ray spectrometer starts to work only four hours after Ranger is launched from Earth. From that time until within forty minutes of lunar impact, it reports to Earth every eight minutes. Then, with less than forty minutes left to go, it steps up its report to one every fifty-two seconds. When the instrumented capsule separates from the "bus," the spacecraft's orientation is disturbed and the gamma ray spectrometer loses its gaze of the lunar surface. Until that time, however, an examination of the lunar surface has been permitted without the necessity of landing an instrument. And the spectrometer has done this sufficiently far away so that its gaze takes in a large part of the lunar surface. This means then that its reports will tell about a large part, not a small part, of the surface—and so those reports will be considered as being typical of the Moon's surface.

The *television camera* starts taking pictures when Ranger comes within 2,400 miles of the Moon. It is switched on earlier, however. A coded burst of electromagnetic energy, a command, is radioed from Earth when Ranger is an hour and five minutes from the Moon and rushing toward it at some 6,000 miles per hour. The transmitter stops sending engineering data and prepares to transmit what the camera will view. A protective cover moves away from the camera's telescope.

Twenty-five minutes and some 3,000 miles later, the camera begins taking and transmitting pictures of the Moon's surface, one every thirteen seconds. On Earth, men view these pictures and see in them a wealth of new detail of the Moon's surface. Their forthcoming visit to the Moon is now brought nearer.

When eight-and-one-tenth seconds from the Moon, the rocket discharges its capsule whose contents are to rough-land. The blast of the discharge rocks the hurtling spacecraft and jolts the camera's view away from the Moon's surface. Before Ranger can right itself, it has crashed into the Moon.

It brings little Earth contamination with it, or with the rough-landed capsule and its contents. These have been decontaminated before launch so that no forms of Earth-like life are likely to injure or change or disturb any form of Moon-life which may somehow be in that silent, seemingly airless, arid, strange surface.

A *seismometer* is the instrument contained within the

hard-landed capsule. It functions like any other earthquake measuring instrument. On the Moon, however, it measures moonquakes. But so sensitive is it that it also measures the shock even of meteorites hitting the Moon. Yet this is the instrument which was landed with a punch equal to impacting granite at 200 miles per hour. It is a tribute to the design and construction not only of this instrument but also of its balsa wood shock-absorber cover, that it will do its sensitive work after so great a jolt upon landing.

Giving the seismometer a voice is its companion, a radio transmitter, complete with silver cadmium batteries. Its amplifier strengthens the seismometer's electronic signals. The transmitter, whose power is only 50 thousandths of a watt, sends these signals via its Earth-pointing antenna to scientists here. If these signals report tremors from *within* the Moon, they may tell whether the Moon's core is liquid or solid, and whether the Moon has a crust similar to Earth's, and perhaps even more information which tells something of our own world's beginnings. The record of meteorite impact on the seismometer and its transmitter will provide first-hand information about this possible hazard to men when they arrive on the Moon. If it indeed proves to be a hazard, this new information will be helpful in providing a means of meeting that hazard successfully.

The Follow-on Projects

Surveyor follows Ranger. Its missions will be continued televising of the Moon's surface, then soft-landing television cameras and their transmitters. There will be soil sampling and testing, and televising of results. The nearing advent of men on the Moon points up the importance of those experiments which sense and measure lunar gravity, radiation, atmosphere and lunar magnetic field through which electronic gear and signals will soon come with men. And there must be still more exact measurements of meteorite impacts from which these men may need protection.

Prospector follows Surveyor. Early missions will continue the televising of the Moon's surface. But these views are of potential landing areas for the astronauts to come. From a later, soft-landed Prospector emerges a Moon-Crawler, a specially designed robot vehicle whose instruments radio and televise to Earth the information they perceive within the 50-mile radius of the vehicle's cruising area. Still later Prospectors return to Earth, bringing with them a solid scientific treasure—a sample of the surface of another world—for study. And the last of the Prospectors brings supplies to the Moon to sustain the men who will have landed there.

Seeing Stars—by Radio

It is via electromagnetic energy that man's scientific instruments make their information known to him. And it was electromagnetic energy which brought to the ancient stargazer his earliest information about the stars and space above him. This same visible range of the electromagnetic spectrum brought still more information from space to the astronomer with his telescope and, later, to the scientist aided by photographic plates which recorded his telescope's viewing.

Electromagnetic energy passes as light through the spectrometers and spectographs and separates into colors whose wavelengths hold meaning for the astronomers measuring their place in the spectrum, and then identifying them and the substance which originated them. Some of these wavelengths come also from the invisible ranges of the electromagnetic spectrum. And

recently there have been wavelengths of electromagnetic energy well outside the visible range of the spectrum, which nevertheless are bringing still more space information to the astronomer. But this time the astronomer perceives without seeing.

Radio Astronomy

From space come radio waves, emitted not from radio transmitters but from natural sources—stars and, oddly enough, sometimes from where there are no stars. These radio waves are identifiable waves of electromagnetic energy in the radio range. Like visible light rays, which the spectroscope identifies with their sources, these radio waves are identifiable with *their* sources. But instead of a spectroscope, it is a radio receiver which picks them up and identifies them by their wavelength or, more exactly, by their frequency.

The radio astronomer tunes his radio receiver to the frequency which he knows is characteristic of an element whose presence and quantity and location in space he seeks: 1420.4056 megacycles for hydrogen, or 327.4 megacycles for deuterium. Then he points the receiver's steerable dish-shaped antenna to the area in space which he wishes to search. Usually the antenna is large. Like the telescope, the larger it is the more waves of electromagnetic energy it can gather and focus. If the antenna does pick up the radio signals he is scanning

for, these are presented to him by his radio receiver either audibly or recorded on a graph.

He maps these, and they form a contour plot. The contour plot of 1420 megacycles would show the location of hydrogen. That would usually be different from the contour plot at 327 megacycles, showing where deuterium is. And both would differ from the plot drawn on the location of 30 megacycle emissions, which would show galactic hot spots or sky temperatures.

If earlier astronomers' eyes and telescopes and spectroscopes could have perceived these radio waves which come from space as do light waves, these instruments of perceiving would have brought them a whole new view of the Universe. For these radio emissions come not only from heavenly bodies which we can see, but also from those we *cannot* see. Perhaps these latter are blocked from our sight because their rays in space are filtered out by intervening masses of gases which absorb them. And radio waves come, in addition, from areas in space where apparently there is nothing. Such an emission may be coming from hydrogen atoms, the principal stuff of the blazing suns of millions of galaxies of our Universe. Or it may be coming from radiation emitted by radio isotopes of radioactive substances, or from solar flares directly from the Sun, or from disturbances resulting from a flare's reaction in some unknown and still not understood magnetic field in space. Maybe it is from a non-heat producing body, instead of

a heat producing one, which has been affected by some enormous heat to which it was exposed.

As for bodies which *do* directly produce radio emissions, our Sun is one. It is a strong emitter, especially during time of sunspots and flares. Venus, Mars, and our Moon emit steady radio waves, while Jupiter discharges electromagnetic energy in bursts. But these are small compared with transmissions from outer space. One enormous source of radio energy is the constellation Cygnus, 270 million light years away. To comprehend just how much radio energy Cygnus transmits, measure it against a typical first-line radio broadcasting station with its output of 50,000 watts; or against a *very* high-power radio transmitter, some twenty times as powerful, with its output of one million watts, or one megawatt. From Cygnus comes an output of radio energy estimated at one thousand billion billion billion megawatts. To produce such a huge amount of energy, according to one theory, two galaxies must have collided head-on. But this theory is disputed because other areas in space have been found also to produce similar huge amounts of energy.

This is not to say, however, that radio signals from space are conveniently loud for the radio astronomer. On the contrary, the radio waves emitted from clouds of hydrogen amount to a grand total, when they reach Earth, of only two watts. Yet these hydrogen clouds are so plentiful they appear to pervade space. In fact, some

astrophysicists believe that our world and other worlds were formed from them. And of these two watts that do reach Earth, only about one billionth-billionth of one watt is intercepted by the radio telescope receiver.

Yet by comparison with deuterium (an isotope of hydrogen), this is a very large amount. Deuterium is much scarcer than hydrogen; its radio emission therefore is just that much scarcer—and just that much harder for a radio telescope to detect than hydrogen's billionth-billionth of a watt. After the receiver has detected so weak a signal, it must amplify its strength so as to be able to present it to the radio astronomer for him to work with. More than that, the receiver must reduce the background of noise which accompanies and sometimes obscures that weak signal. This noise can come from space or can be generated within the receiver itself. Reducing that noise and building up the signal is called "increasing the signal-to-noise ratio." So well-engineered and built are these instruments, and so skillfully operated, that we now have a radio telescope range of a billion light years.

Radar Astronomy

The radar astronomer also uses a radio receiver, but in addition he uses a radio transmitter, too. He uses this transmitter to send bursts of electromagnetic energy in the direction of the nearby worlds he wishes to examine.

These bursts hit, bounce off, and are reflected back to his receiver. It is much like sunlight reflected from the Moon's surface—these waves of electromagnetic energy are received by our eyes which thereby see the Moon's surface. The radar astronomer can reflect radio waves of electromagnetic energy against the surface of cloud-shrouded Venus. The return, called the "echo," is only a tiny fraction of the strength of the original signal. But it is amplified by the receiver until it can be recognized as a piece of intelligence.

Too often there also is amplified a hash of static and other unwanted noises which smother the echo and its meaning. This has happened when Venus was scanned by radar. Then it was necessary to use an electronic computer. Painstakingly the computer works over the jumble of noise in which the signal of intelligence is buried until the noise is worked off and the intelligence emerges. At last the computer produces a "picture," really a composite of numbers, which represents the surface of Venus hidden from sight by its perpetual clouds.

Usually, the receiver and transmitter are at the same location, are one station (monostatic). Two-station (bi-static) radar astronomy will come when the receiver is contained in a spacecraft sent to the area of the body to be studied—a technique which promises better use of power, and more and clearer information.

The *radar* astronomer finds answers to "What is the

Electronics, Key to Exploring Space

distance of that object?" and "How fast is it traveling, and in which direction?" or "What type of surface does it seem to have?" The *radio* astronomer's information, on the other hand, tells him where and how large the object is, how bright it is, and the composition of its own radio spectrum.

Electronic Communications in Space

I n its use of electromagnetic energy, radio is well-suited for communicating information over the great distances of space. And it does it accurately so that scientific information loses none of its value. It does it with such speed that the information remains meaningful and commands can be acted upon in time. And it does it with such flexibility that instruments can send their information to Earth while spacecraft and planet may be hurtling through space in opposite directions.

Distances of millions of miles are short for these radio waves of electromagnetic energy. Like any traveler through space, they encounter few obstacles. The faint, pale beam of light from a very distant star—pulses of electromagnetic energy, too—has traveled an enormous distance. Presumably it traveled in a straight line; and for those millions of years of travel at 186,000 miles per

Electronics, Key to Exploring Space

second it encountered nothing which interrupted it in its journey to the inner surface of your eye as you chanced to look in just that direction at just that instant in time and space. The energy of that beam causes a pattern of intelligence to be delivered to your brain, a pattern you learned to identify as "a star" or perhaps a particular star.

How Radio Works

Waves of electromagnetic energy come from the radio transmitter of a Moon-landed seismometer or of a probe in space. These waves are man-made. Their wavelengths, longer than light's, are in the *radio* range of the electromagnetic spectrum. They pulse at a much slower rate than does light, even though the frequency of this pulsing may be millions of times per second. Their energy is supplied from batteries accompanying these distant, untended radios. Electrons which have been stored in these batteries furnish this energy.

As these electrons flow through the radio they are grouped into patterns which will represent intelligence at the receiving end of the communications link. These patterns may be the same as those shaped by air waves when a voice speaks into a microphone. Or perhaps the shape is characterized by breaks—like the on-off of a computer's binary talk, or the dots and dashes of code. These shaped groups of electrons retain the

REFLECTOR



FLASH LAMP
RUBY ROD

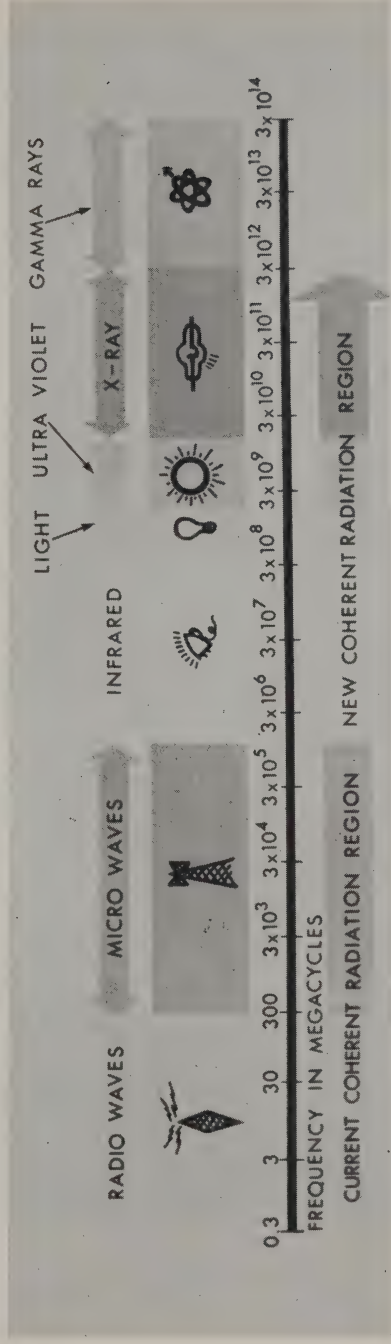
LIGHT BEAM
OUTPUT

RADAR

LASER

NASA

The laser—which can concentrate light with such intensity that it can burn a pinhole in steel—makes light waves manageable for space communication in the manner of radio waves, but on a beam of *light*.



NASA

The electromagnetic frequency spectrum shows pulsing rates of electromagnetic energy well below and beyond the narrow range we can see as "light."

EXTERNAL
GALAXIES

STARS

INTERSTELLAR
GASES

SUN, EARTH AND
SOLAR SYSTEM

BLUE $\lambda 3100$ - $\lambda 5000$ YELLOW $\lambda 5200$ - $\lambda 6600$

RED $\lambda 6300$ - $\lambda 6750$ INFRARED $\lambda 7200$ - $\lambda 8400$

NASA

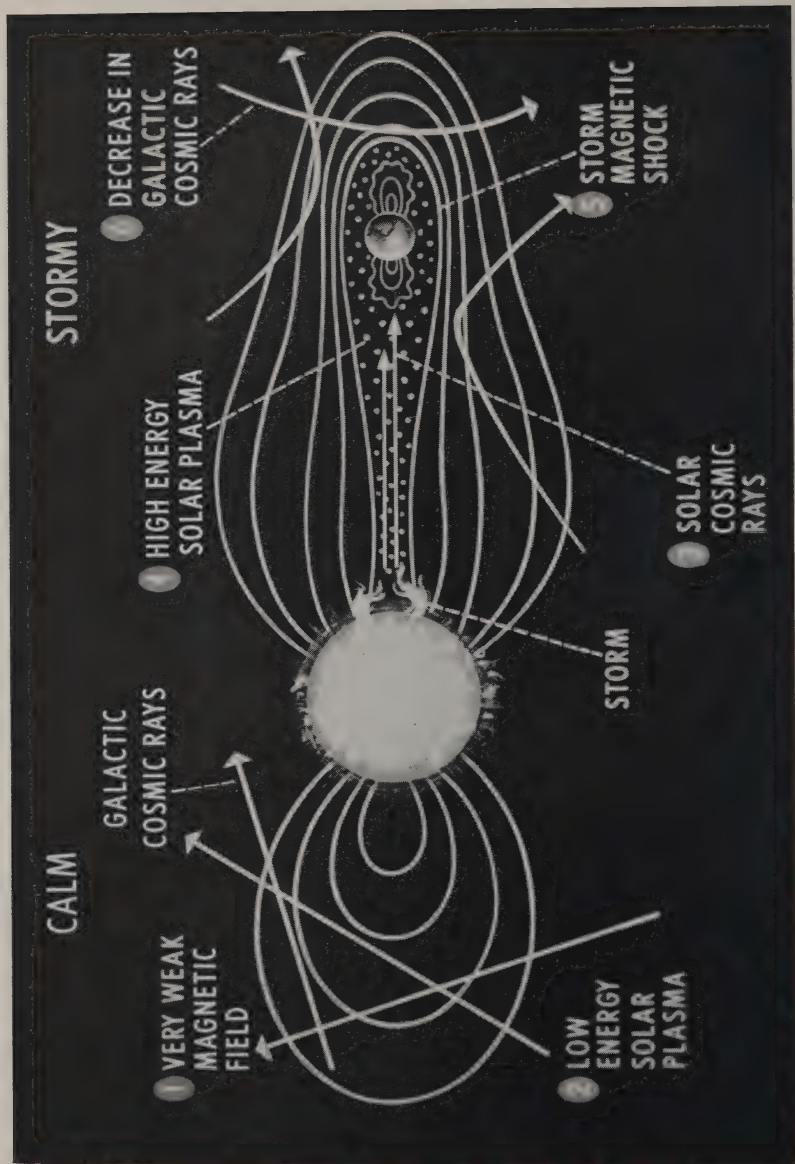
Astronomers on Earth explore the universe and examine its composition via different wavelengths of electromagnetic energy—symbolized by λ . Here shown is the same area in space viewed at the different wavelengths of different colors.

GEOPHYSICAL AND SOLAR STUDIES



NASA

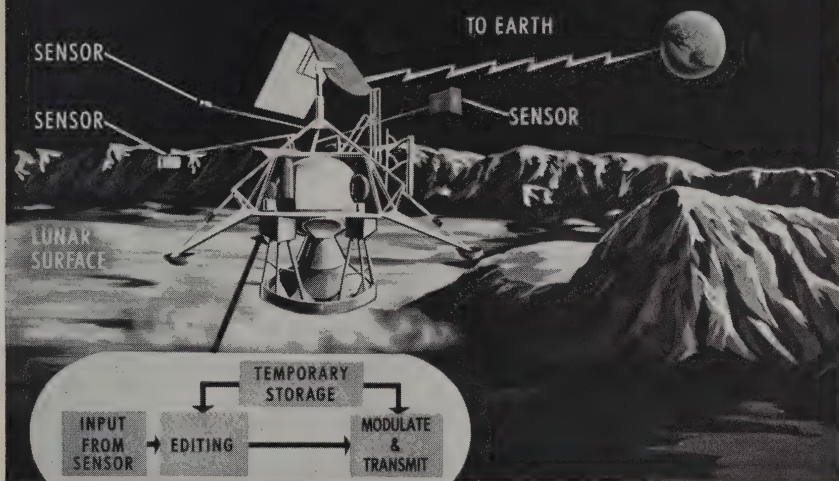
Earth is greatly influenced by the Sun. Knowledge of our own planet and the space surrounding it must include knowledge of the Sun and its effects.



NASA

The Sun's influence also permeates the region between planets—interplanetary space. Man will explore here, too—first by instrument, later perhaps in person.

DATA ACQUISITION AND TRANSMISSION



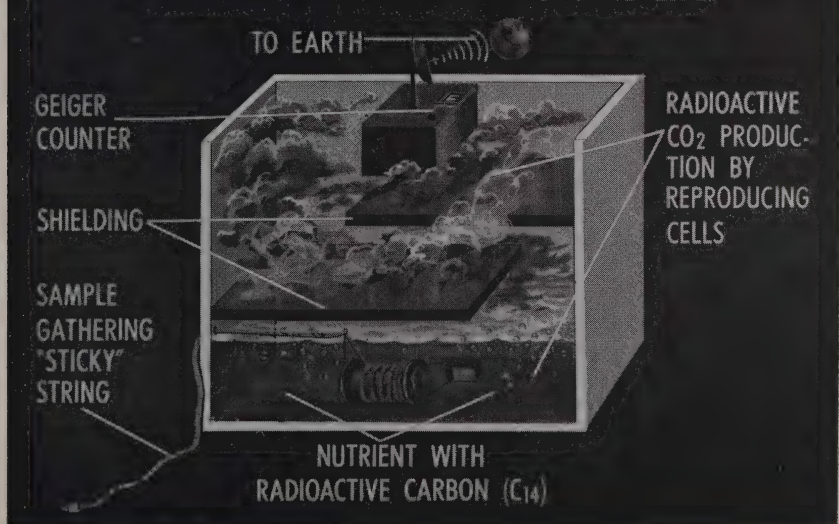
NASA

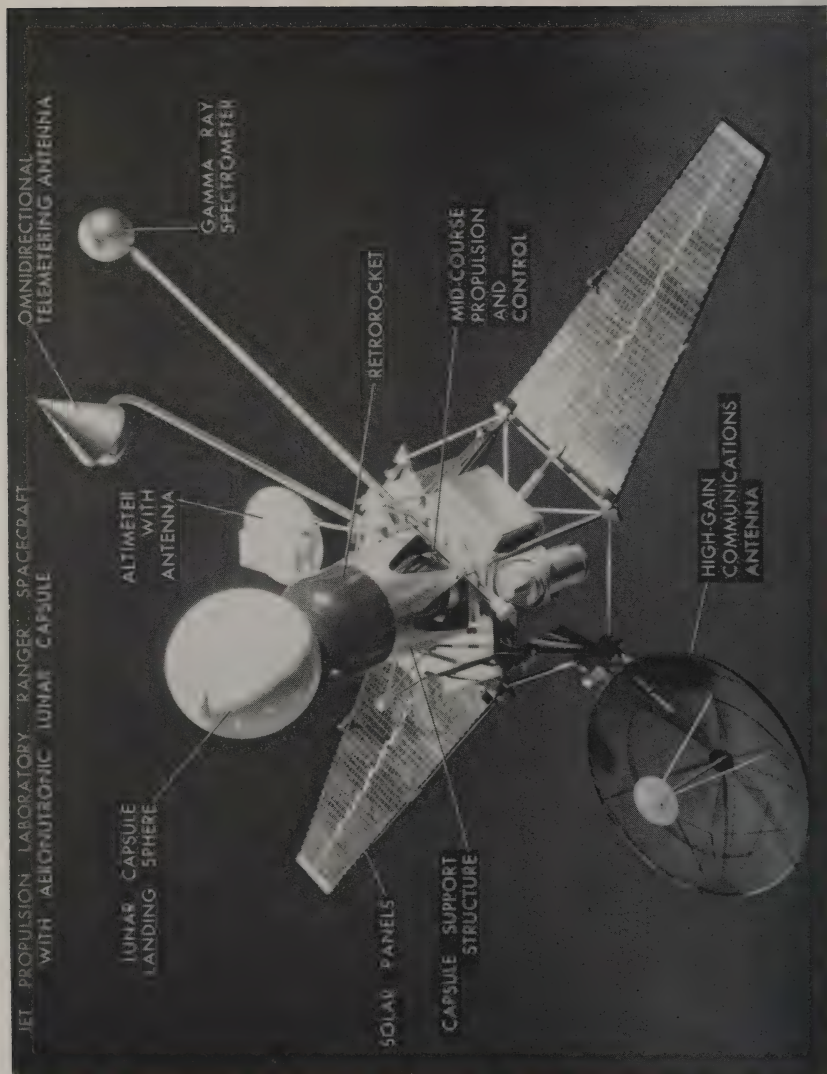
Unmanned instruments, landed on other worlds, will sense and transmit to Earth the information men need before going there. Both acquisition and transmission of such data are accomplished by means of electronics.

Cutaway drawing of unmanned instrument designed to detect simple life forms on other worlds and radio those findings to Earth.

NASA

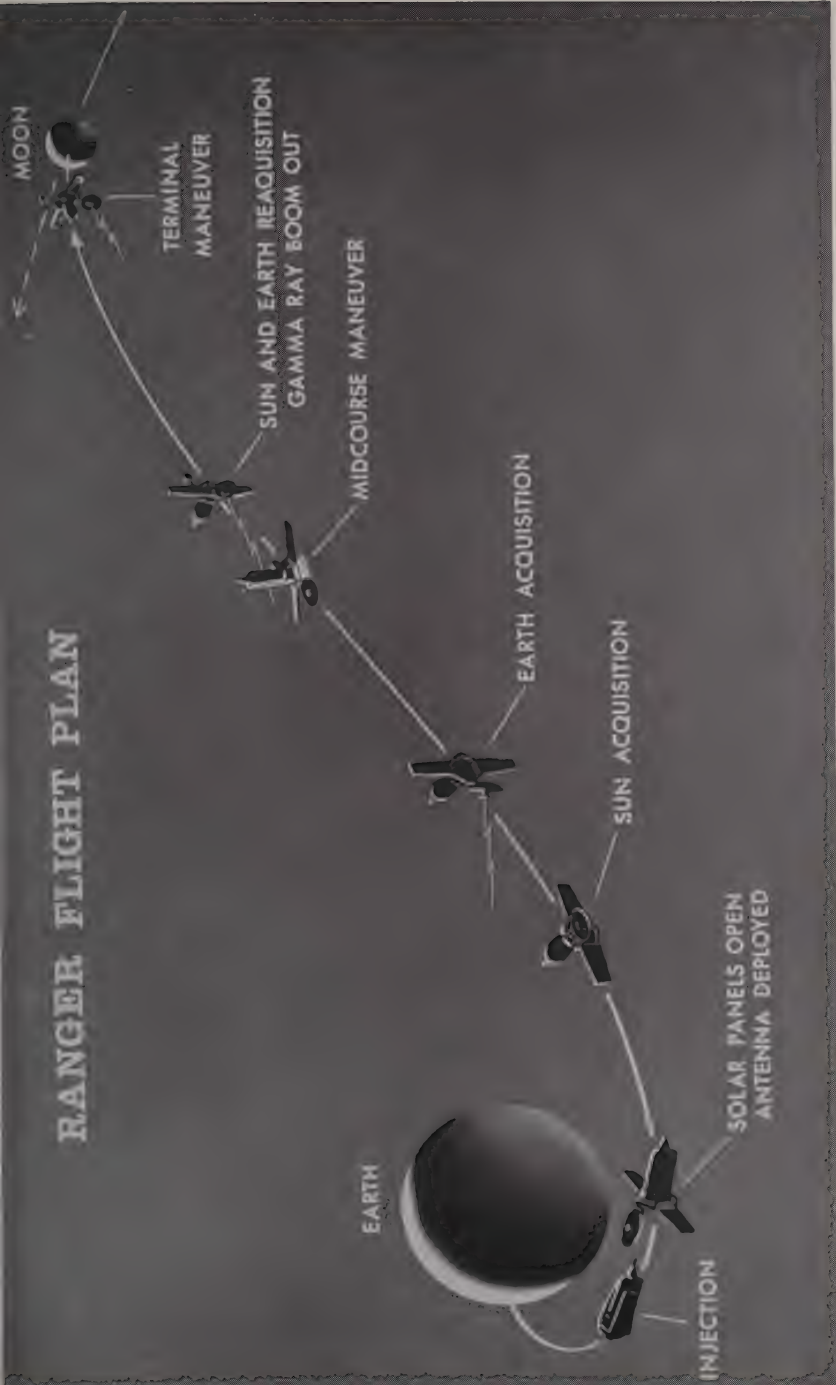
DETECTION OF EXTRATERRESTRIAL LIFE





JPL, courtesy of Aeronutronic Division, Ford Motor Company
Close-up of scale model of the Ranger spacecraft.

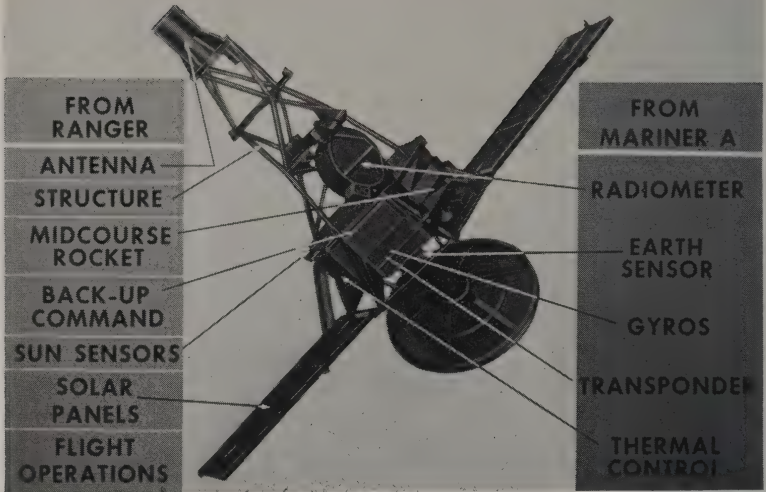
RANGER FLIGHT PLAN



NASA

Electromagnetic energy—radiated naturally by Earth and Sun—is employed by men to radio commands to maneuver Ranger in space, correcting its flight path to the Moon.

MARINER II EVOLUTION

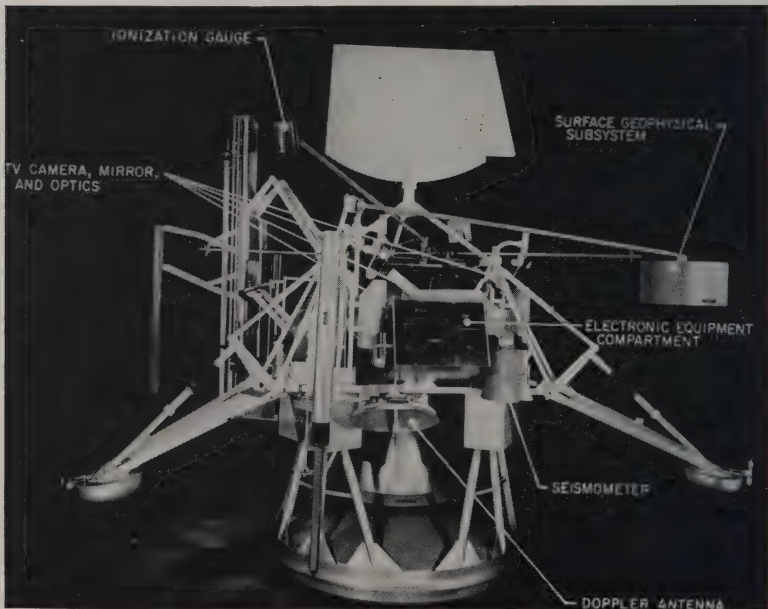


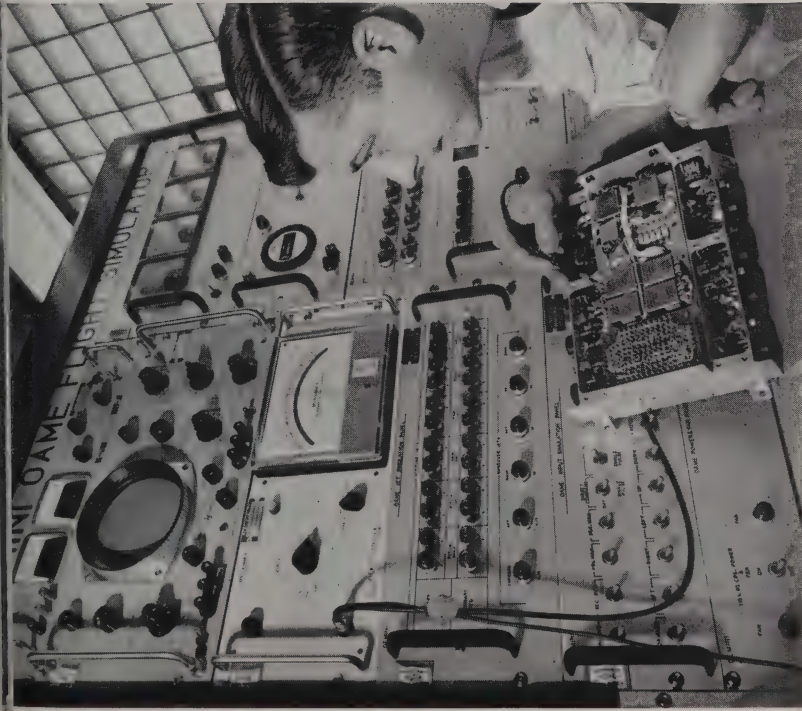
NASA

Instruments and techniques from one spacecraft may be adapted for use in later, more refined, spacecraft. Mariner II incorporates equipment used earlier in Mariner A and Ranger.

Surveyor A, one of the spacecraft series that follows Ranger, the Moon hard-lander. Surveyor is designed to soft-land, then radio and telecast its observations of the lunar surface.

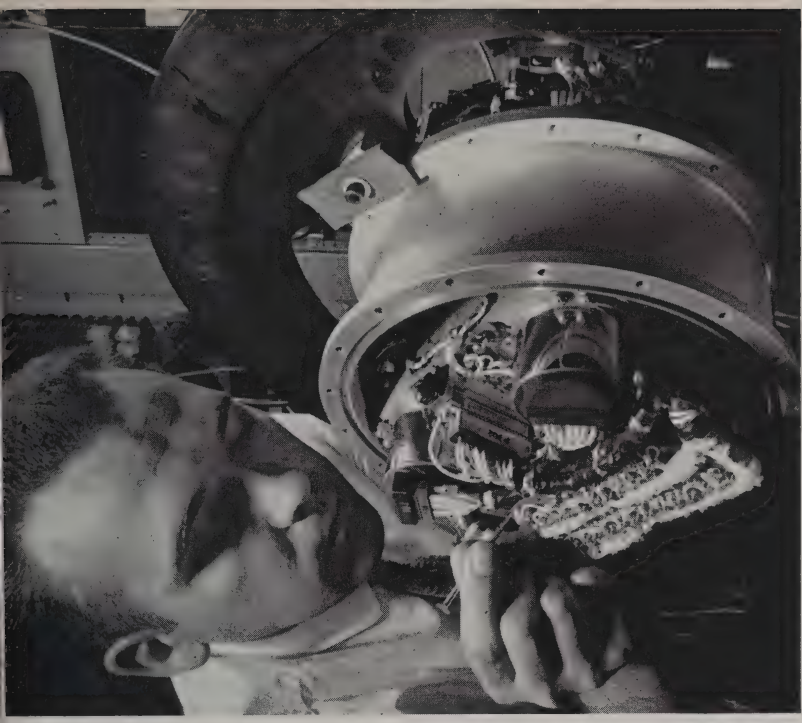
NASA





Honeywell

Spaceborne electronic equipment must be small, but precise. This miniature electronic computer is dwarfed by the ground flight simulator used to test it.



Honeywell

These three tiny gyroscopes, part of the rocket flight control system that successfully launched Tiros II, sensed even the slightest deviation in trajectory.



M.I.T., Lincoln Laboratory

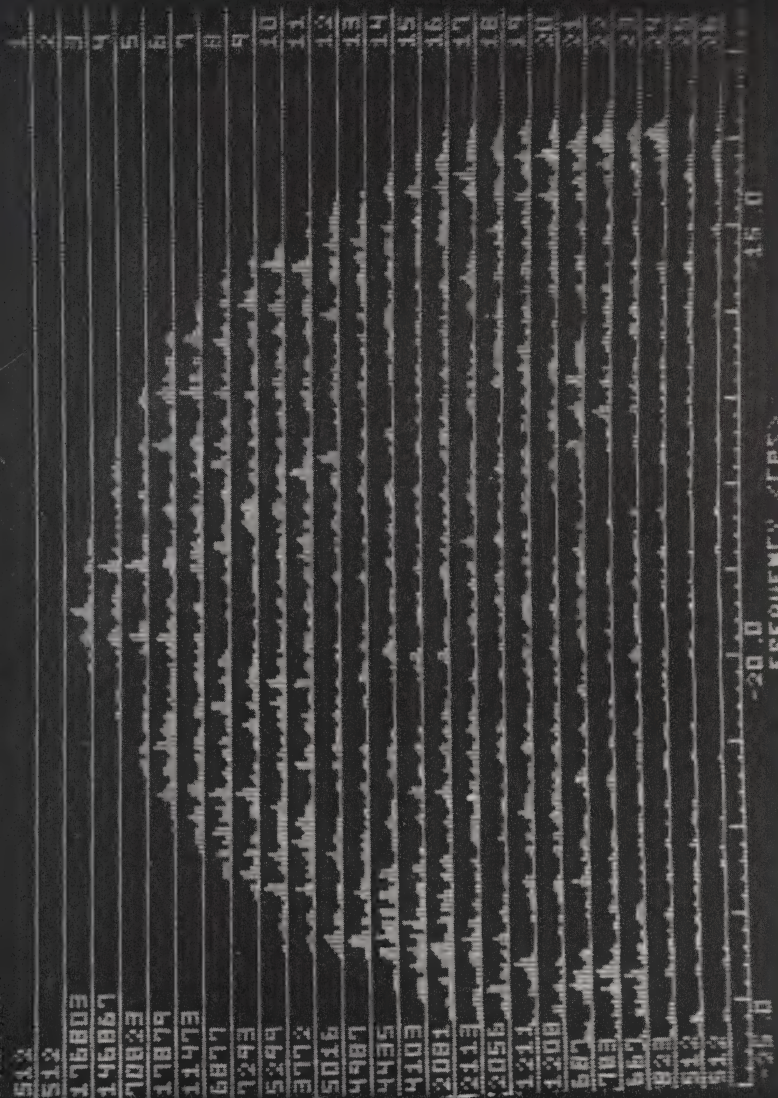
The Millstone Hill radar antenna gave man his first "sight" of Venus' surface by sending bursts of electromagnetic energy that penetrated its thick shroud of clouds, struck the never-seen surface, and bounced back.

2

MOON POWER SPECTRUM

SALE FACTOR

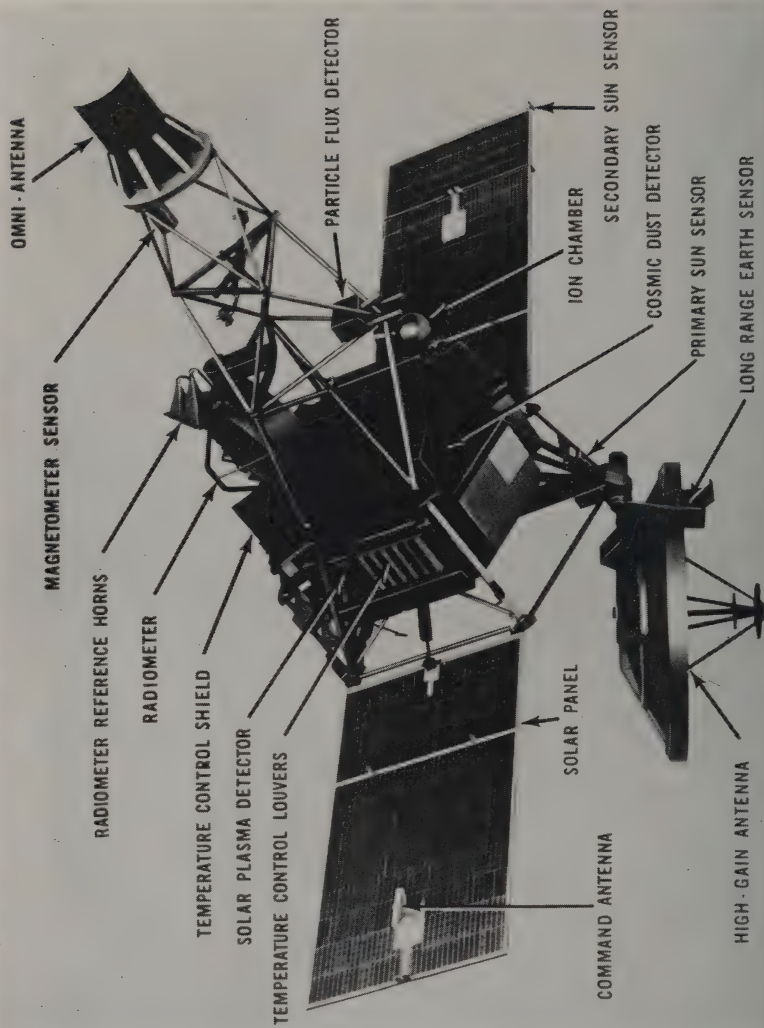
WILLIAMS



SEEKING

M.I.T., Lincoln Laboratory

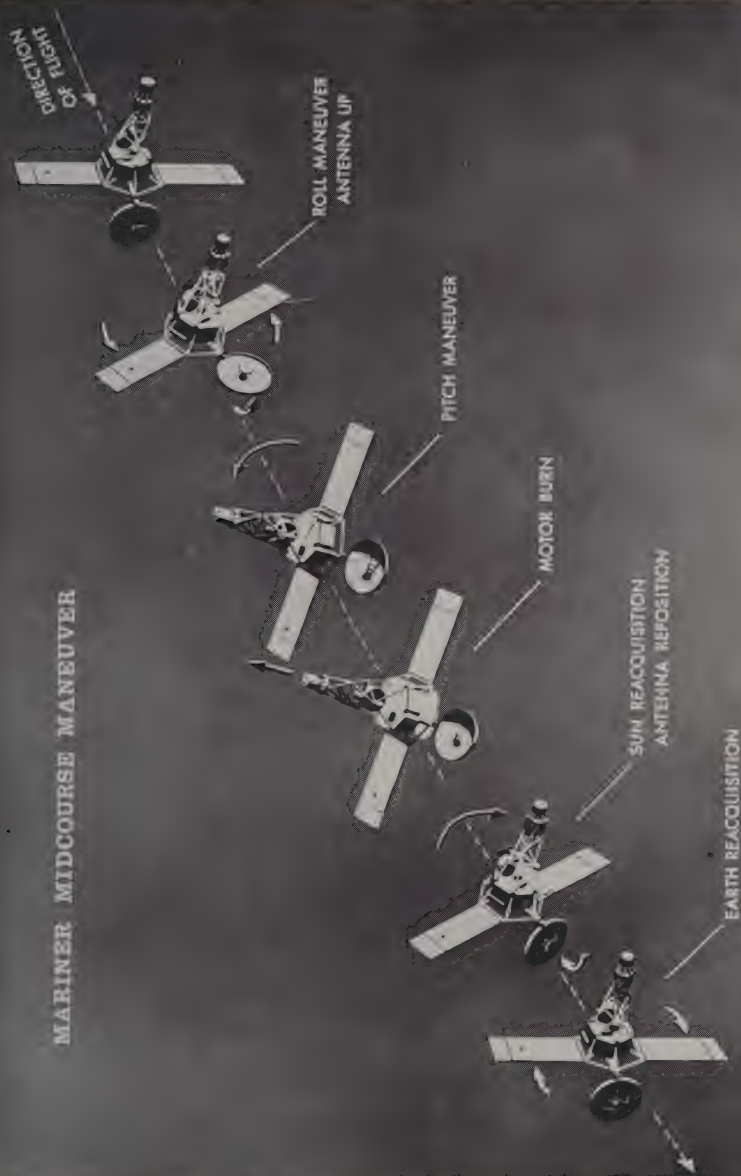
M.I.T.'s Millstone Hill radar produced this map of the moon's surface radio-activity.



NASA

Mariner is the spacecraft that brought a scientific triumph in 1962 by its outstanding accomplishment of its mission—the Venus fly-by.

MARINER MIDCOURSE MANEUVER



NASA

Mid-way to planet Venus, Mariner II was radio-commanded to perform this complicated series of maneuvers, to correct its course to target. It obeyed perfectly.

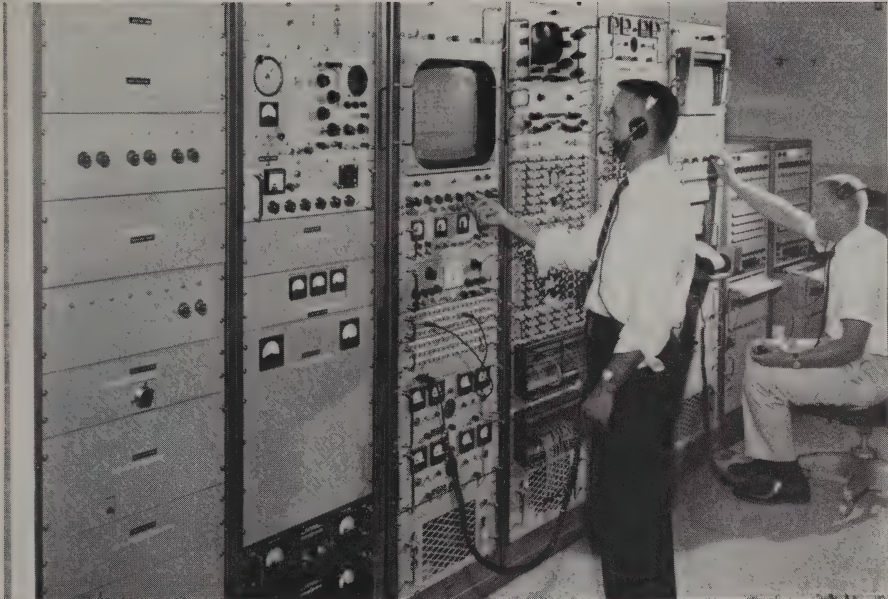
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 DSQSGSGGQXRDXHAOX DXQ XZAIZAVQKQZDZXXDLKKDRA Z DSQSGIGGGQXRDNZO
 X DXQ XZAIZAVQKQZG XDRZSDRA Z DSQSGIGGGQXRGLZOX DXQ XZAIZAVQK
 QDGXXDRDXDRA Z DSQSGIGGGQXRGLZOX DXQ XZAIZGAVAQQSXZXXDRDZDRA S
 ZSQSGIGGGQXRDRQOX DXQ XQAIZGAVQKVA XDRDZDRANGDSSQSGIGGGQXRDIZO
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 DSQSAQGGGXRDSQOG DXQ XZARZAZZKZDZXXDLKADRA Z DSQSGIGGGGXRGXQO
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 Q XZAIZAZZQKDG XDRDSDRZ Z DSQSAQGGGXRSLAOK DNQ XZAIZAZZQKSSZ
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 DSDIZLZ ZSQSSQGGGQXRSDQHZ DXQ XQCHZGGGHZQQSX XDRDIDRXIS ZSQSDHGG

micro wave

infr
red
radiation

NASA

Enlarged facsimile of coded Mariner II tape transmitted December 14, 1962, on the Venus fly-by. Circled information shows coding of microwave and infrared information.

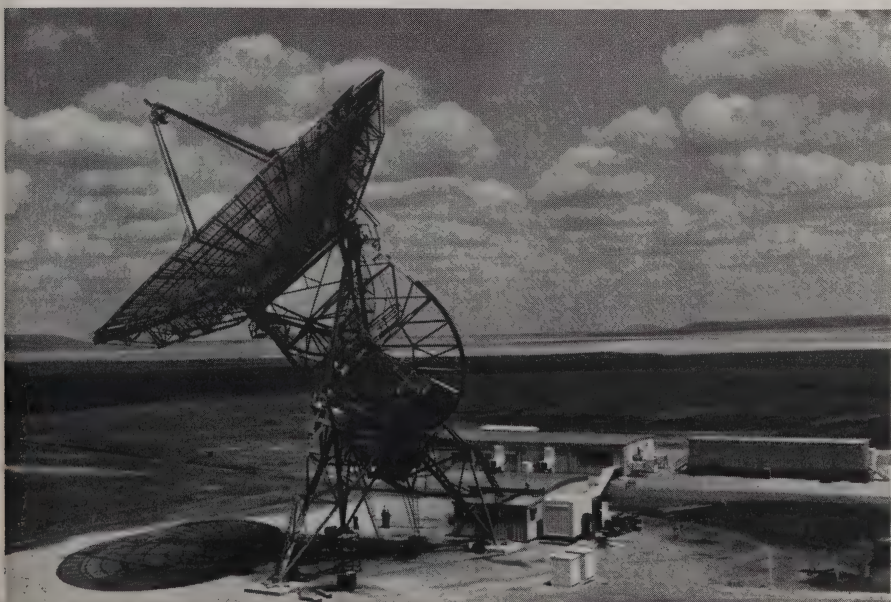


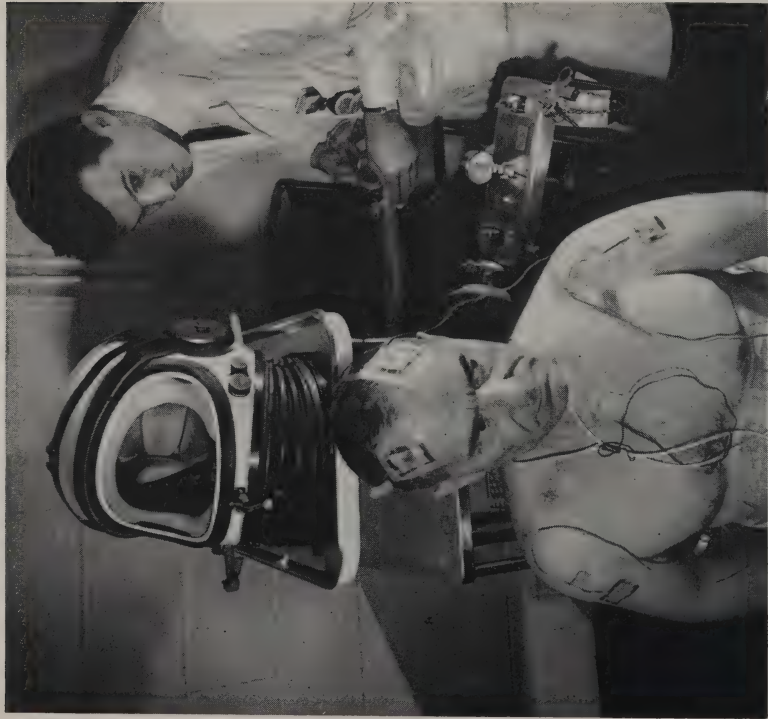
NASA

Tracking station for Project Mercury astronauts at Wallops Island, Virginia. Scientific and engineering information radioed from spacecraft is picked up by telemetry receiving equipment.

Deep Space Instrumentation Facilities (DSIF), like this one at Woomera, Australia, track spacecraft on lunar and planetary missions and acquire the data they transmit to Earth.

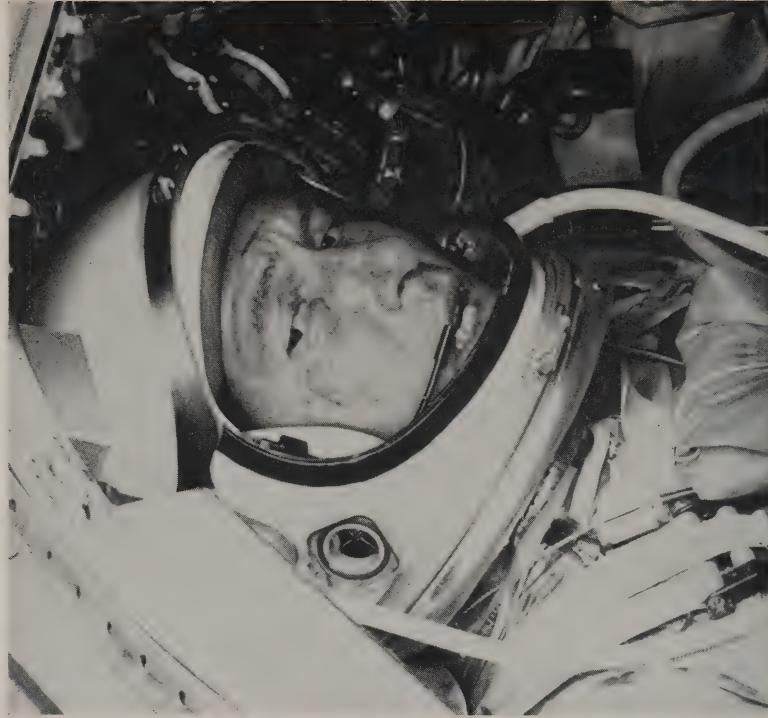
NASA





NASA

Temperature biosensors are tested on a space environment engineer during development of space suits to be worn on the Moon by Project Apollo astronauts.



NASA

Astronaut Walter Schirra's helmet microphone has a biosensor attached—an electrically heated metallic strip for indicating rate and depth of respiration.

shape of their patterns as they flow through the radio's transmitter—where extra energy is given for spanning a great distance—and into the metal antenna of the radio transmitter. An oscillator within the radio makes these grouped electrons race up and down the length of that antenna, at a prescribed *frequency* of thousands or even millions of times per second (kilocycles or megacycles).

As they race up and down, a field of force is created outside the antenna, and streams away from it. This field of force is the electromagnetic energy which will traverse the space between transmitter and receiver, even worlds apart. Its shape keeps corresponding to the shapes of the groups of electrons within. And it is in the form of waves because all the while it is streaming outward from the antenna it is moving up and down the length of the antenna, following the racing electrons within.

These waves are what we call *radio waves*. The distance between their crests is called their *wavelength*.

Radio waves flow outward from the antenna always at the same rate of speed, 186,000 miles per second, or to use radio terms, 300,000,000 meters per second. Waves of high frequency are bunched closer together than are waves of low frequency because there are *more* of these waves flowing outward per second. The distance between their bunched-together crests is shorter. To say it another way: high frequency means short wave length—or short wave.

(When frequencies grow so high that they are very much higher than radio frequencies, the waves grow so short and the frequencies so great that their energy becomes visible. These frequencies are in the *optical* range of the electromagnetic spectrum. The first color which emerges as the frequencies increase is red. This color grows out from infrared, whose frequencies are not quite fast enough for us to be able to perceive their energy. Watching an old iron stove heat up to a glowing cherry red will demonstrate this process. The greater the heat, the greater the energy. As the waves of energy become more rapid, they become visible. And as the frequencies grow higher, the colors change from red to orange, then yellow, green, blue, indigo and finally violet.

The intense heat from the Sun produces the mix of colors which results in the colorless brightness of sunlight. Frequencies grow still higher as they approach and reach the intense gamma rays. These are the rays which are the objective of our Moon shot's gamma ray spectrometer, seeking them among the Moon's rocks.)

The higher these frequencies and the shorter their wavelengths, the straighter becomes the line in which these waves of energy travel. Light is produced by the energy of electromagnetic waves whose frequencies are so high and whose wavelengths are so short that this energy becomes visible to us. Light, then, should (and does, we believe) travel in a straight line. So do radio

waves of *very* high frequencies. Perhaps these lines are not quite as straight as light coming through space from a distant star. But they are straight enough to use in radioing information to Earth from a planet or the Moon or a spaceship.

The Moon seismometer's radio then will be designed to transmit to Earth on a very high frequency. Its short waves of electromagnetic energy will travel on a straight line. And if the seismometer's antenna is pointed Earthward, these waves will be beamed in that direction. When there is such a focusing of radio transmission, only a fraction of the power used in a wide broadcast is needed. And so the transmitter for a space instrument or a spacecraft, which employs very high frequencies and which beams its transmission, can be powered by a small, lightweight battery. This is desirable; aboard a spacecraft, inches and ounces count.

When this low-power radio signal reaches Earth, it is a weak one indeed. But the shaped patterns which were formed back at the transmitting end remain the same. The receiver's antenna receives them; they are amplified over and over, but without distorting their meaning. The pattern of intelligence has remained unchanged from sender and transmitter, through space, to receiver and user.

How Radar Works

Radar also uses transmitter and receiver, but usually right at the same location. Frequently these employ the same dish-shaped antenna for both purposes: as transmitter, when it sends a brief burst of very high frequency radio waves that travel in an almost straight line to target, and as receiver when it gathers in these waves after they have bounced back from target. This echo bouncing back appears as a bright dot on a kind of television tube. It represents the location and distance of the object. If there are a sufficient number of bursts of energy reflecting from an object, these form an image of the target on the radar screen.

To compute distance between radar transmitter and target, measure the time from sending the signal until its echo returns. Don't forget to divide by two: it's a round trip. Then divide the remainder by the signal's speed—300,000,000 meters per second. For fairly close-by targets, accuracies in millionths of a second are needed. These can be supplied, so precise are the characteristics of the electron and its use.

How Television Works

Television is still another way of communicating intelligence electronically. The picture it produces is more truly a picture than is radar's. With television, as with

our eyes, electromagnetic energy in the form of light bounces off the object we view. These light rays are gathered together and a lens focuses them. In television, the lens is that of a TV camera. The image which these light rays form is focused on the face of a special kind of radio tube, the cathode ray tube.

The cathode ray tube converts this light from electromagnetic energy into electrical signals. These electrical signals take the form of electrons grouped in patterns which represent intelligence—this time, visual intelligence—the pattern of the image. This is a “step down” of electromagnetic energy, from the optical range of the electromagnetic spectrum down to the radio range. Now the intelligence can be transmitted by radio.

This converting of an optical image into an electronic charge pattern permits it to be stored on tape. And when on tape, transmission can be delayed, if necessary, without losing the information.

At the television receiver the groups of electrons, still in their transmitted pattern, are stepped up in the electromagnetic spectrum until they convert to light, which appears on the television screen. Since the patterns have remained the same since transmission, the image on the screen is the image that was transmitted.

Space Brains—Electronic Computers

Signals received from space are intelligence, but they are not yet converted into a form intelligible to the men who use their information. This, of course, does not include voice or television communication, but it is true of the greatest part of communications from space, that coming from scientific instruments. These sense a condition and report it by using varying voltages of electromagnetic energy. But varying voltages, as such, hardly suffice to inform a scientist. They must be “translated,” usually into numbers.

There are great quantities of numbers resulting from the communication of scientific information from space. Each sensor at work in each spacecraft supplies its share. And spacecraft have missions lasting for weeks, months or even years. In addition to the problem of translating voltages into numbers, there also is the prob-

lem of working with so many of these numbers. This is a problem of arithmetic. It requires assembling and "reducing" this arithmetical information until at last its essential meaning emerges with accuracy from what was originally a vast welter of data.

Ideal for accomplishing this work is the electronic computer. What were originally space signals of varying voltages can be changed by the spacecraft's encoder into number data which a computer on the ground can use. Usually these are put on magnetic tape. This is the information, still jumbled but usable by the computer, which is fed into the computer. The computer does the arithmetic and reduces this mass into its essential meaning. It does in hours or a few days what would have taken a scientist weeks or months to do. The time he is saved from such laborious, time-consuming, routine arithmetic he now can use to much better advantage: to think about what this information may mean and then how to act upon it.

The Digital Computer

The digital computer is the type which, as its name implies, works with digits, numbers. It is therefore the type most often used in this work of reducing data. (Another type of computer works best with information which is varying, such as the continuing change in distance as a spaceship approaches the Moon. Since it must

Electronics, Key to Exploring Space

furnish its solutions to such problems in the form of an analogy, this computer is called an "analog" computer.)

The digital computer works with measurements, quantities, amounts. Despite its reputation as a "brain," and despite its formidable appearance of complexity, it really is quite simple in its workings. The basis is "yes or no," "on or off." And that depends simply upon whether there are electrons flowing through a wire in the computer at that point in the problem. If, in a sense, the electrical current is "on," then the answer is "yes." If not—if it is "off"—then, "no." Two digits correspond to these two conditions: 1 for "yes" and 0 for "no."

Computer Language

This system of using these two digits, the *binary* system, is the most common language of computers.

Of course, a binary number usually is longer than just 1 or 0. But it is made up of only 1 or 0, no matter what its length. The position of each 1 or 0 indicates its value. Reading from right to left, the first digit position has a value of 1; each digit thereafter represents 2 or 2 raised to increasingly higher powers. The total is the sum of these values added together. (Zeros remain zeros, as they do in any kind of multiplication.)

In binary language, then, 111 would be 7. How? The righthand digit is 1 and remains 1. The next digit represents 2 to the first power, or 2. The next digit repre-

sents 2 to the second power, or 4. And 1 plus 2 plus 4 equals 7.

A longer sample binary number is 101101. Read it, from right to left, like this:

1	0	1	1	0	1	digits
2^5	2^4	2^3	2^2	2^1	1	value
32	0	8	4	0	1	multiplied by 1 or 0

Added together, they equal 45.

And so a binary number of 101101 in digital computer language equals 45.

Roundabout though that may appear to be, it really is simplest. The computer is not a mechanical calculating machine. It works electronically—not by an electric motor turning over wheels and gears and mechanical parts, but rather by electrons racing through a wire or not going through these wires at that particular instant. Such speed cannot be matched by anything mechanical. Such speed is what gives the computer its great advantage. Such speed more than offsets what apparently is the cumbersomeness of binary language.

How a Computer Works

Addition, subtraction, multiplication and division are the primary work of the computer. To do it, it has an arithmetic element. It also has a place for storing information given to it. There is another place where its

Electronics, Key to Exploring Space

instructions are stored and where they are issued, too. And it has a facility for the taking in of new information and the giving out of answers to problems.

"Programming" is the name for electronically instructing the computer what it is to do. These instructions are detailed indeed, for the computer has no imagination. It functions step by separate step, each step furnished and in the right order precisely according to the program's instructions.

But the computer takes those steps so quickly. Each step in multiplication, for example, takes only some twenty-five millionths of a second; for addition, only half that. It reaches for information stored inside and delivers it in eight millionths of a second. This is its "access time." And even this brief access time can be shortened by rearranging the computer's wiring. Whatever the computer does, it does accurately. This is very largely because it is not a mechanical but an electronic instrument, and electrons obey their physical laws without fail.

Computer in the Command Link

Computers solve other kinds of problems, of course. One of these has to do with correcting the flight path of a space probe when it is about halfway to its destination. Just before that time, the radars which have been watching the flight path of the spacecraft begin to

pour these tracking data into the computer. The computer uses this information to calculate the spacecraft's location in space. Then it compares that location with the information stored within it before the flight began, to determine if the spacecraft now is at the location where it should commence its flight path correction.

When the spacecraft reaches that location, the computer follows instructions and instructs the spacecraft to start its mid-course correction maneuver. The computer may do this by notifying a man that "now" is the time for him to radio that command to the spacecraft. If, however, the computer is linked directly to the radio transmitting system—as many military guided missile systems are linked—the "now" is told to the transmitter. A coded burst of electromagnetic energy streams out to the spacecraft and, at a speed of 186,000 miles per second, soon reaches it. Inside the spacecraft's receiving antenna, electrons instantly assemble into groups whose shapes correspond to the patterns of electromagnetic energy touching the outside of the antenna. Commands shaped at Earth are received millions of miles away.

The tiniest of weak signals, these commands are amplified almost instantly so that they are strong enough to do work inside the spacecraft's computer. Here is no monstrous machine; its dimensions are only a few inches. But the circuits within are sufficient for it to direct the spacecraft to perform its mid-course maneuver.

While the computer was watching the spacecraft's trajectory via its radar, it not only compared that trajectory with what it "knew" that should be, but also it calculated how much correction would be needed, and how the craft should maneuver in order to achieve that correction: How much roll and how much pitch to point it anew; the amount of mid-course motor burn to transfer it, now facing the right way, to its new path which will take it to target. From Earth computer to Earth radio transmitter, through space, to spacecraft receiver and spacecraft computer goes this precise information. The spacecraft's flight controls obey. The craft maneuvers, alone in space, then begins its new course that takes it to target.

After this maneuver the spacecraft's computer awaits its next major task. When the spacecraft comes within range of the target planet, the computer calculates and issues commands to control the encounter sequence. During the encounter sequence the spacecraft's scientific instruments determine surface temperature, atmosphere composition, cloud layer study, magnetic fields, the "how much" and "where" of charged particles, density and direction of cosmic dust, intensity of solar plasma in the vicinity of the target planet. From the spacecraft's radio transmitter comes this intelligence. It is brought to transmission at the instruction of the spacecraft's computer.

13

Telemetry: What, Why, How

Telemetry is the science of taking measurements, within a spacecraft or of conditions outside it, and radioing that information to Earth where it is interpreted and made ready for use.

The telemetry system of a spacecraft is a series of electronic equipments which change voltages coming from the sensors into computer language, and then radio this information to Earth for use by the computers there.

These voltages coming from the sensors are raw measurements of their sensing. But these go to the data encoder, a computer-like instrument in which there is an oscillator for each sensor. The oscillator converts the voltages into a signal, an output signal, one of low frequency.

The encoder changes these signals into a code, into computer language. Binary numbers are coded into

“words” of ten digits. Ten “words” make a “frame.” But to be complete, the signal has eleven words to the frame: one all-zero word is inserted for identification that this is a frame, and complete. There is extra precaution against the running-together of information between words, which might affect the accuracy of interpretation: each word has two extra binary digits which are used in synchronizing the words.

That is the language of the spacecraft which is used to radio scientific information such as that from Mariner’s experiments, for example. These are the cosmic ray experiments, electron experiment, proton experiment, plasma experiment, ultraviolet spectrometer, Geiger counter telescopes, Geiger counters, miscellaneous counters, ion chamber, cadmium sulfide detectors, magnetometer, radiometer, and the cosmic dust experiments.

Experiments for magnetic fields or for temperatures are among those which may use *analog* sensors on a scientific spacecraft. But this analog information must be changed into the pulses of digital information before transmitting it Earthward. An analog-to-digital converter changes into pulses the voltages coming from analog sensors.

Engineering data relating to the flight are often produced in analog form also, but it too is converted from analog into digital form. Yet with all the data to be radioed from a spacecraft, there usually is only one radio

transmission even though there may be several transmitters aboard. This is not to say that all instruments are always reporting, or that each instrument reports as often or for as long as all others. A satellite which acquires information on one side of the world may have to wait to radio it three-quarters of an hour later and half a world later where a special receiver awaits it. This delay problem is solved by a tape recorder within the satellite. Its hour-and-a-half's accumulation of information is spewed out at high speed in only five minutes while it ranges over the receiving station.

A deep-space probe does not have these same problems of timing transmission, but there may be areas of time when transmission should be delayed because of local physical conditions. Instead of circling Earth as a satellite does, the probe watches Earth and its receiving stations circling below while it speeds farther and farther away. Within the probe is a clock system, part of the data encoder, which synchronizes and programs the time for transmission of information from each sensor. In some spacecraft a rotating switch called a commutator makes electronic contact with each of the sensors in turn—or perhaps divides the transmitter's carrier wave into segments and uses each segment for a piece of information coming from each sensor.

The carrier wave is a part of the radio transmission. It is the powerful carrier of the weaker signals of intelligence which ride piggyback on it. If the carrier wave

is made wide enough, several sensors can send their information on it at one time, by multiplexing. This means that each sensor becomes, in effect, a separate little transmitter, different from all the others only in that its frequency is just a little higher or a little lower. In this way, several of these sub-carriers can ride on the same wide, powerful main carrier wave without interfering with each other. The equipment in the spacecraft which accomplishes this combining is called the Central Signal Processor.

At the receiving end each of these separate little transmissions needs its own separate little receiver. A filter there separates each of these sub-carriers from the main carrier. The one big receiver is constructed as if it contained separate receivers, each accommodating each one of the sub-carriers.

If the instruments are to report one at a time, then each sub-carrier changes the main carrier so as to represent intelligence. This changing is called *modulation*. The modulation might be increasing or decreasing the carrier's frequency—frequency modulation; or its amplitude—amplitude modulation. Sometimes there is phase modulation too, but most often it is frequency modulation which these spacecraft telemetering systems use.

This is the shaped radio wave which streams out from the antenna of the spacecraft's transmitter and touches the antenna of a radio receiver on Earth. Electrons in that receiver group themselves to correspond to the in-

telligence, and their energy is represented on the face of an oscillograph or is recorded on magnetic tape—most often in digital data form, ready for use by a computer.

Biosensing and Telemetry

One of the most complex and important instruments in a spaceship is the man. In addition to his words there is information being radioed from him by way of the biosensors fixed on or in his body. If it appears that he is succumbing to any of the dangers of space flight, perhaps he can be helped. The more specific that information is, the better it can be used.

One clue is given by the report of his respiration. How much faster or slower is he breathing? How much more shallow or more deeply? His lungs will fill more deeply and more frequently if they are trying to get more oxygen—a sign that his oxygen supply is failing and his body is receiving too little. This is *hypoxia*. If the supply cuts off, his lungs' action becomes violent. The opposite to that condition is *hyperventilation*, or over-ventilation; it accompanies fear or panic. If this rapid breathing also is shallow it may mean that his body temperature has risen to fever heat, whatever the cause. Breathing that is intermittent tells of fainting, certainly a perilous situation for a man alone in space.

How can you instrument a man so that these respira-

tion conditions will be detected and radioed to earth.⁹ Unlike the instruments of a spacecraft, his biosensors must not hinder his movements while he operates his spaceship. Also, the apparatus should not be complex.

Project Mercury has used an instrument which fulfills these requirements. It is a thermistor, a metallic strip which has an electric current passing through it which keeps it at a temperature of about 200° F. in still air. It is attached to one of the helmet microphones, in line with air being exhaled by the astronaut as he breathes. Each exhalation of breath cools the thermistor, and this cooling changes the arrangement of the molecules within the metal, offering more resistance to the electrons of the electric current passing through the thermistor. This increased resistance means a change in voltage. And it is this which can be sensed. That weak little signal is amplified and transmitted. Detailed sounds of the man's breathing are radioed to Earth.

How fast or how hard a man's heart pounds tells not only of changes from normal, but also provides a clue as to why. A hearing aid type of device is attached to the astronaut's chest. This hears the chest-wall vibrations which have been generated by his heart's thumpings, and relays these to the capsule's telemetering system for radio transmission to Earth. Unfortunately, also radioed to Earth with these sounds are any other sounds within the sensor's hearing, including speech sounds when the man is talking.

The astronaut's body temperature is an excellent tell-tale if there is trouble aloft. If it is much higher than normal it may mean that the temperature within the cabin or within his space suit is too high. And too much humidity raises the man's body temperature, too, by reducing the amount of evaporation taking place on the surface of his skin. But more than these, his high body temperature may be telling of conditions less apparent and perhaps more difficult to correct: emotional state, infection by virus, poisoning, dehydration. Too low a body temperature may tell of another condition difficult to correct from Earth: bleeding or its frequent companion, shock. The biosensor for measuring body temperature is again the thermistor, positioned within the body or sometimes underarm.

Other biosensors measure the astronaut's body conditions and these, too, are telemetered to Earth: his blood pressure, his skin temperature, measures of changes in skin resistance which show mental stress or alertness. An electroencephalogram measures electrical waves given off by his brain. Their frequency patterns reveal if he is conscious or if he perhaps is suffering some neurological disturbance.

PIAPACS is the acronym for "psychophysical information acquisition processing and control system." This system proposes fastening the astronauts' biosensors not to or in him, as at present, but in his flight suit and head-gear so that he has greater comfort and freedom. The

Electronics, Key to Exploring Space

data which these biosensors furnish will be reduced by computers not only to inform the monitors on Earth, but also as the basis for computing predictions and even correction of conditions affecting the astronaut and his efficiency.

Telemetering extends far into the distant future. At that time there well may be entire communities of Earth people then living on—or under the surface of—another world. There the community will be entirely enclosed, protecting its Earth-origin members from an environment hostile to them, and supplying them with their own kind of sustaining environment. Located throughout the great container will be sensors, descendants of the sensors we use today in monitoring the life-support systems of our astronauts' capsules—oxygen supply, noxious gas removal, air temperature and pressure and humidity and circulation. Many of these future sensors will be of the warning type, to alert the inhabitants for immediate action. But there will be other kinds, too—informing not only monitors there but also telemetering their sensed information to Earth-based monitors whose long-range records of that controlled environment will affect plans for later communities on that or still other worlds.

Command: Remote Control of Spacecraft

During a Project Mercury flight, men intently monitor the instruments on consoles before them. These dials and oscilloscopes indicate what the biosensors and life-support instruments in the space capsule above are reporting about the man in space. If these Earth instruments read "Danger!" and show that the astronaut is unable to help himself, these men can help him. They radio a command to the satellite, send it a coded burst of electromagnetic energy.

This is indeed energy, and as such it can do work. Received by the satellite's radio, this energy is amplified or strengthened and sent to the spacecraft's computer where its meaning is recognized. There, too, is where its energy triggers the computer to respond. Its response

is to follow its program which corresponds to the command. Step by step it issues instructions to the flight controls of the satellite, which cause it to break orbit and descend at safe angle and speed for re-entry into Earth's atmosphere where it then deploys its parachute and gently lowers the helpless astronaut safely to Earth.

Types of Commands

That type of command is only one of many kinds. Commands radioed from Earth often are to unmanned spacecraft where the response may be to throw a switch which turns off a scientific instrument or turns on the spacecraft's transmitter so that a high-speed burst of information pours out, in five minutes, what the craft's instruments have observed and tape-recorded in a flight around the world. Mariner's mid-course motor burns to the microsecond of time specified by exact command from Earth, whereas only a "Go!" is needed to trigger Ranger's approach mode which directs it to turn itself around, warm up the gyros and the television system, remove the cap from the camera's telescope, et cetera.

Nor are all commands in *real-time*; that is, for immediate execution. Ranger's is one kind which is stored within its computer, delayed for execution until it is needed or until it is convenient to transmit it. A command can be given automatically from within the spacecraft, too. Ranger's radar altimeter does that when it

tells Ranger that "here" is the altitude at which to release its instrumented capsule.

Antenna

The correct orientation of Ranger and Mariner are important to the execution of their maneuvers. Each carries two types of transmitter antennas, a directional antenna which is a single metal rod, and an omni-directional antenna which is umbrella-shaped. If the spacecraft is oriented properly, its directional antenna points directly to Earth and the signal sent from it is received strongly. But if the spacecraft maneuvers and its directional antenna no longer points Earthward there is a danger that its transmissions to Earth may be lost and not be received there. Use of an omni-directional antenna reduces that danger. This is why Mariner is commanded, before it begins its mid-course maneuver which reorients it, to switch from directional to omni-directional antenna. Then, when the directional antenna once again points to Earth, the transmitter switches back to using it again, for this antenna is more efficient and uses less power than does the omni-directional antenna.

For Ranger to be properly oriented in space, its Earth-sensor is required to seek and find the electromagnetic energy being radiated from Earth, within only four hours after launch. In the sensor's search, it is not the sensor but Ranger itself which rolls about in the

seeking to find and lock on to those emanations from Earth. If it succeeds, then Ranger will be oriented in space as planned, and its directional antenna will be pointing directly to Earth. It is possible, however, for electromagnetic energy from the Moon to confuse Ranger's Earth-sensor. If the sensor locks on to this energy by mistake, then Ranger will be improperly oriented and its directional antenna will not be pointing directly to Earth. Signals transmitted by that misdirected antenna will be weak when received on Earth. So that communication with Ranger will not be lost under such circumstances, Ranger also carries an omnidirectional antenna—one which will do its work, although not as powerfully as the directional antenna, in almost any direction.

For Ranger IV, it is the Earth station at South Africa which commands a switch from omnidirectional to directional antenna. If Ranger's response is received more strongly, it means that Ranger is oriented properly and so its directional antenna is pointing Earthward. But if Ranger's response is weaker, South Africa commands it to "look again" which means to accept a command that overrides its present instructions, and to commence rolling by which it resumes search for Earth by its Earth-sensor.

Command Sites

DSIF is the abbreviation for Deep Space Instrumentation Facility, the name of NASA's Earth stations which work with probes. Their shorter name is Deep Space Stations. There are three, one at Goldstone, California; one at Woomera, Australia; one at Johannesburg, South Africa. Each is one-third around the world from the other so that as Earth turns and takes one station out of sight of the probe, another station is being brought into sight to train its 85-foot diameter, dish-shaped antenna on the distant spacecraft.

NASA's ground station sites for the manned Project Mercury orbitings are spotted around the world. Six have ground command-control. All feed their data into NASA's Goddard Space Flight Center near Washington, D.C. Some of these data are processed and some are relayed in real-time—immediately—to the Mercury Control Center at Cape Kennedy, Florida, where flight controllers are monitoring these manned flights from lift-off to recovery.

NASA's Earth Satellite Instrumentation Stations circle the world in their work with unmanned scientific Earth satellites. Each station has a command transmitter; each connects to the system's control center at the Goddard Space Flight Center.

Commands to interplanetary spacecraft come from the Space Flight Operations Facility of the Jet Propul-

sion Laboratory in California. The commands, however, are relayed to one of NASA's three Deep Space Stations.

Sending the Command

The command itself usually is digital, or binary, computer talk—a series of pulses of electromagnetic energy. Each series is usually made up of thirteen of these pulses. This includes the pulse which synchronizes this series with the spacecraft's computer and the pulses which designate which one of the spacecraft's components this command will affect, and the command itself.

Some commands used during the mission are standard; read-out of engineering instruments is one. DSIF stations keep these ready, prepunched on teletype tape. Before they are used, however, Command Verification Equipment checks them for error. Then the command is taken from the memory part of this equipment and sent to the command modulator, where the word bits are synchronized. Here also the command sub-carrier and its carrier, or radio frequency, are modulated. Together, they form the completed signal. This burst of electromagnetic energy leaves the modulator, shoots through the wave guide, slams against the inside of the 85-foot dish, bounces off and hurtles into space, overtaking the speeding spacecraft in one giant leap.

Commands and Accuracy

Although an Earth station transmits far fewer commands than a spacecraft telemeters data, the Earth station's information has to be much more accurate. When data are telemetered, one or two errors to every thousand bits transmitted is permissible. Commands, however, must have fewer than one bit error for every hundred thousand bits transmitted. This is made more difficult to accomplish because command errors can also come from electrical noise. And electrical noise comes from the communication process itself. It can even come from the environment: from radiation and temperature, sometimes from the condition of vacuum that is in space. Other electrical equipment within the spacecraft may generate noise, too, as can their power supplies as well. And error can come from breakdown or malfunctioning of the spacecraft's equipment which receives and identifies and acts upon that command.

But if all goes well, these bursts of electromagnetic energy are received by the spacecraft, undistorted. They are strengthened and sent to the decoder. There the command is examined for its address. This reveals which of perhaps many commands this one is. And this in turn tells what the command consists of: "on-off" or "how much" and to which equipment within the spacecraft this particular command applies. There it goes—and in most instances the spacecraft then telemeters to Earth

a coded acknowledgement as if to say, "I hear and obey."

Commands to an OAO

The Orbiting Astronomical Observatory is a satellite designed to orbit Earth above the atmosphere and make astronomical observations on the ultraviolet range obscured to astronomers below. After getting into orbit, the OAO orients itself according to its computer's program so that it will observe where and what is assigned to it. It does its orienting by its star trackers.

These are photoelectric cells which seek the electromagnetic energy coming from only those particular stars they are instructed to find. When they have found the star, they amplify the energy received from it and use it to signal the attitude motors of the spacecraft for roll or yaw or pitch—just enough to keep the craft oriented so that the star tracker can keep locked on to its distant star.

But when all the data that are useful for the present are at last telemetered to Earth, the astronomers may want a new set of information. Then radio commands will point the OAO craft into a new direction. Its star trackers will train on other stars assigned to them. Upon command, the TV camera will switch on or off, and its transmitters, too. Engineering instruments respond: temperatures and pressures and voltages of equipment

aboard. At intervals come reports of the spacecraft's orientation, distance from Earth, time elapsed in flight, all to synchronize with information already sent to make it just that much more accurate.

This ability to command different experiments applies to other spacecraft, too. In this manner, one spacecraft can perform experiments which result from information which it gained only a little earlier—and while still in flight. But it is the intelligence of a man on Earth which recognizes the desirability for the follow-on experiment and which commands it, even though remotely from such a great distance. Better than this arrangement is one which will have the man there in space *with* the experiments, monitoring them at firsthand.

Commands to a Moon Soft-Land

Pilots who later will be making manned landings on the Moon can get their flight training, first, on Earth by radio-commanding an unmanned TV-equipped spacecraft to a soft-landing on the Moon. The craft's TV camera views the Moon during most of the flight. The controller on Earth uses this picture to keep the vehicle on target. As the spacecraft nears the Moon he uses the TV picture in aligning the vehicle properly for a landing and in judging the distance which is closing between the vehicle and the Moon's surface. When the vehicle is almost there, a radio signal takes 1.3 seconds to reach

Electronics, Key to Exploring Space

from Earth to spacecraft or from spacecraft to Earth. Yet the fast-draining power supply of the craft allows only one television picture to be transmitted per second (instead of the usual 30 per second we see on our commercial television).

Using TV command rather than an automatic process may be the method to soft-land unmanned spaceships on the Moon—until the day a man is aboard to pilot the ship in person. Even though all the equipment needed for TV command is very complex, in the long run it may prove to be still less complex than the equipment needed for a fully automatic soft-landing. The piloting system simplest to use on board is, of course, a man.

15

Tracking a Spacecraft

To track a spacecraft means to follow the invisible track it makes as it orbits Earth or arcs through space to intercept the Moon or a planet or as it goes deep in toward the Sun. Unless you track, you cannot know—certainly with any accuracy—where your craft is when, for example, it telemeters, “Radiation in lethal quantities here.” You must know its position before you can command it to begin its mid-course maneuver or to prepare for a landing or to unmask its TV camera’s scope.

The changes in the path of an orbiting Earth satellite tell where the pull of gravity is stronger and where it is less—revealing, among other things, Earth’s shape. As for manned craft, Project Mercury astronauts and their successors trust their lives to your knowledge of where, precisely, they are at each instant.

Equipment

Radar tracks the Mercury capsule; and other Earth satellites have a spacecraft-transmitter and Earth-receiver technique which makes good use of the closeness to Earth at which these craft orbit. But the probes and fly-by's and deep-space craft which travel increasingly farther from Earth require a different set of electronic equipment to follow their paths into space.

Radar can hardly be expected to pick up so small an object as a probe speeding away from Earth some twenty-five million miles distant—and then to bounce back a piece of that signal with sufficient strength to have it reach Earth and still be usable. In place of radar there is a combination receiver and transmitter called a *transponder* within the spacecraft. It receives the Earth signal of electromagnetic energy and, instead of bouncing some of it back as radar does, it returns a signal of its own, promptly. This technique does use something of radar's purpose of getting back a response to a transmission. But its method is quite different. The response, instead of using a fraction of the original energy transmitted, uses fresh energy supplied from within the craft. Thus it greatly increases both range and accuracy over radar's capabilities. A transponder also contributes greatly to the remarkable accuracy of measuring the speed of spacecraft via a technique known as Doppler.

Doppler

Anyone who has heard the whistle of a train that is rushing toward him, and then has heard the much lower pitch of that same whistle as the train thunders past and recedes into the distance, has heard Doppler shift—the basis for electronically measuring the velocity of spacecraft with an accuracy that measured Mariner II's velocity to within one-tenth of an inch per second at a distance of 53,000,000 miles.

Change in frequency is the key to this process of Doppler shift. The train whistle's sound waves were at a higher pitch as the train approached the listener because they were being pushed together by the movement of the train. There were more sound waves per second and that, of course, means they were at a higher frequency. While the train receded from the listener, the sound waves of its whistle traveled with it. Now there were fewer waves per second because they were being stretched out in time and distance. Fewer waves per second is the same as saying "lower frequency." These lower frequencies produced a lower tone. Both the lower tone of the lower frequencies and the higher tone of the higher frequencies could be heard because these were sound waves: their rates of vibration were slow enough to be audio frequencies.

Radio frequencies, however, are necessary for use in

spacecraft tracking. For one reason, radio waves travel farther than do sound waves. But these radio waves can pile up or stretch out just as sound waves do, creating a Doppler shift. The listener in this case is a radio, the train is the spacecraft and the whistle is a radio transmission of electromagnetic energy at frequencies in the range of millions of cycles per second.

The signal sent from the ground station very likely is at 890 megacycles. The spacecraft's transponder receives it, multiplies it by 96/89ths and instantly returns it. The ground station receives this space signal now of 960 megacycles. (These figures of 890 and 960 will soon give way to 2110-2120 and 2290-2300. In any event, there will continue to be a difference between the frequency used to the craft, and the frequency the craft uses to respond. If the same frequency were used for each direction, the ground station might confuse one for the other.)

The received signal is compared at the tracking station with another signal, one which is being manufactured there at exactly the 960 megacycle frequency also being transmitted by the spacecraft. But now there is a difference between the two; the received signal is at a lower frequency because the spacecraft's speeding flight away from Earth is stretching out the distance each second, and so the radio waves also are being stretched out each second as they stream out from the receding craft.

When these stretched-out waves are received and compared with the known frequency at which they actually were sent, it appears that their frequency has shifted lower. This difference is the apparent Doppler shift. How much is that shift? How great is that difference which this comparing reveals? The greater the spacecraft's velocity, the greater the shift.

That shift, that difference, is measured with great accuracy. It then becomes the basis for calculating very directly what, therefore, the velocity of the spacecraft must be.

Range and Direction

The rate of speed at which electromagnetic energy travels remains at 300,000,000 meters per second, no matter how high or low the frequency. This makes it possible to compute the range between Earth and a spacecraft: Measure how many seconds it has taken the signal to travel from instant of transmission to instant of return from the spacecraft back to Earth. Multiply by 300,000,000 meters. Then, as with radar, divide by two, because this is a round trip. The product is roughly the range—"roughly" because "time out" and "time back" may differ slightly due to the speed of the craft as it moves away from Earth.

Direction also is known as "ground antenna pointing angle." When the signal from the spacecraft is being re-

ceived strongest, the big dish-shaped antenna must be pointing right at the craft. Read the antenna's vertical and horizontal angle to determine the angle of direction.

And these are the angles which the next Deep Space Station uses to point its antenna as it is brought by Earth's rotation into position to continue the tracking. These angles are called, in this use, the "apparent angle of arrival of signals."

Now you have the necessary information to predict where the spacecraft will be in the next hour, the next day, or the next week. You know its present location, its range and direction. Doppler has furnished you the craft's velocity, the direction and speed of its movement. From this information, you can plot the future path of the spacecraft.

That path should be the one calculated long before launch. If it is not, the Earth computer notes the discrepancy, and calculates the amount of maneuver and mid-course motor burn needed to put the craft on the correct flight path. And this becomes the basis for the radio command to a Mariner type of spacecraft to perform its mid-course maneuver.

In future, spacecraft may track themselves, their star sensors noting position and then commanding course corrections, through the craft's computer, to the flight controls. Even now, some missiles may be doing this during their comparatively brief flights. This method of star sensors commanding corrections will soon be used

also by the OAO satellite for its attitude corrections as it makes its observations above the atmosphere.

Data Acquisition

The main function of the DSIF, the Earth stations that track probes, is to make sure the giant antenna always points toward the spacecraft so that outgoing commands or incoming data are not interrupted. But if the antenna should lose the spacecraft, it is pointed to the area where the craft is known to be. Then the antenna commences to search at that point via a spiral scan, spiralling outward from there until the craft is encountered. Another method is the sawtooth scan, the antenna sweeping back and forth across a rectangular area.

The spacecraft found, the antenna locks on to it electronically and tracks it automatically. It does this via electromagnetic energy, and in much the same manner as a spacecraft uses its star sensors or Earth-seeker and Sun-seeker. These use electromagnetic energy to note and compare, and then to correct and command changes in course or attitude.

The DSIF's giant dish antenna, locked on to the spacecraft and tracking it, receives telemetered information from the craft. This is data acquisition. How well it is done affects the accuracy of the data given to the scientist to work with.

Data acquisition by stations tracking scientific satellites orbiting the Earth use slightly different equipment than do the DSIF stations, but great accuracy in tracking is also required. The satellites, small and orbiting close to Earth, come speeding up over the horizon. They are in sight of their own tracking stations for only a brief time. Yet their data must be acquired. The stations must be ready for them, must point their antenna right to where these speeding little targets will be received. These stations are the Minitrack stations, located in North and South America, Australia, England and South Africa. They use the interferometer method to learn the satellite's angle from the station—information of interest also to the next Minitrack station in the satellite's orbit path.

The interferometer method uses two antennas, spaced on a North-South line, and two on an East-West line. The satellites carry a transmitter and antenna which radiate a signal at 136-137 megacycles and whose carrier's frequency is fixed. This is the signal picked up by the station antennas. The delay in time of receiving this signal at each of the two lines is measured. It tells the satellite's angle from the station, and this information is sent to the next Minitrack station.

The angle of location from Earth, for a satellite orbiting Earth, provides a means of tracking the satellite continuously. With a deep-space probe, however, that angle eventually becomes unusable. While the craft

is yet near Earth, this angle changes frequently and enough to be noted. But when the spacecraft has moved far out, the angle changes only occasionally and little. Then the tracking switches to Doppler.

Optical Tracking

The ten-foot Baker-Nunn camera has tracked satellites since Project Vanguard, sometimes so precisely that its results become the standards by which to check the accuracy of electronic tracking. The camera photographs a satellite in flight against a background of stars, and its shutter is timed to open and close on a precise schedule. This divides the photographed trace of the satellite's flight into segments, and each segment is studied to determine the angles between satellite and stars in the background. The time of each photograph gives the clue to the positions of those background stars, so that the satellite's position, which is in relation to them, then becomes known too.

Communications Net

The location of the spacecraft being tracked and the acquisition of its data being transmitted are relayed between stations of a network and their central operating headquarters.

NASA's net of ground stations is tied together elec-

tronically by telephone, microwave radio and by teletype, which is especially useful for sending tracking data to the Central Computing facility. The focal point for Project Mercury's communication system is the Goddard Space Flight Center where dual high-speed computers do their work promptly and communicate it on a real-time basis to their twenty-one stations around the world. These computers determine the astronaut's orbit and predict his new orbits. They recommend what should be done if anything goes wrong during flight; and they predict where he will come down if his capsule must be taken out of orbit "right now."

Project Mercury tracks only one craft at a time. But Minitrack, monitoring the unmanned Earth satellites, has the problem of tracking many of these at one time. And each has its own orbit. These orbits vary, too, in their angles as well as in apogee and perigee.

Soon there will be more than one deep-space probe to be tracked at one time. Simultaneous reports from similar spacecraft that are widely separated will prove so valuable that it is almost certain this multiple tracking technique will be used. The task may be lessened by the use of more antennas, but the value of the computer will increase even more—not only to aid in the problem of tracking several spacecraft during one period of time, but also to accommodate so much more information being telemetered from all these.

Manned Interception of Manned Spacecraft

We give our military the task of protecting our country from an attack from space. To carry out this assignment they too must know about that portion of space from which an attack might be made. And they must be able to intercept a spacecraft whose payload may be instruments not for knowledge but for destruction.

Their first task is to track and identify every man-made object circling Earth. This includes not only satellites but also fragments of earlier shots which still orbit. Fixed radars detect; moving radars track; Baker-Nunn cameras photograph. Phased-array antennas scan and track, electronically, without moving. Radio "fences," like those Minitrack employs, send fan-shaped areas of electromagnetic energy into the sky to detect satellites passing through. All objects in space around Earth, friendly or not, working or not, whole or debris, large or tiny, are known and followed and their new paths predicted by range, azimuth (direction), elevation, range rate, and angular rate.

The U.S. Air Force's Space Track Research and Development unit at Hanscom Field, Massachusetts, is one of the chief contributors of this information. U.S. Navy's Space Surveillance Facility whose Observations Center is at Dahlgren, Virginia, is another major contributor. Both teletype their information to the Space Detection and Tracking System at the headquarters for North

Electronics, Key to Exploring Space

American Defense located at Colorado Springs. There electronic computers furnish information and recommendations to men who then decide if manned interception is necessary.

Manned interception easiest to conduct is that in which a sort of space ferry will rendezvous with a friendly spaceship in order to resupply it or to exchange crews—much as a spaceship some day will intercept the hurtling Moon, join with it by landing on it, and resupply the crew of scientists there. The ferry's radars and computers electronically sense and provide information which becomes the commands for precise maneuvers necessary for rendezvous. This command information becomes, in the last remaining distance to be closed between the two craft, range, velocity, angle and angle rate. Accuracy now is vital, and the radars and computers must be so versatile that they furnish this information, accurately, whether the range is twenty-four nautical miles or only fifteen feet, and range rates at 200 feet per second or zero.

At the beginning of the terminal phase—the closing between the two spacecraft—the distance is some 200 nautical miles. Such distance requires the use of a transponder in the friendly spaceship to which the ferry is going. But when the distance closes to some twenty or thirty miles, the ferry's radar locks on. The friendly spaceship cooperates further by carrying a reflector, the better to echo the ferry's radar.

But what if this is an emergency, a rescue mission? Routine supply missions use a parking orbit of some eighteen hours before transferring to the orbit of the target. Eighteen hours may be too long for this emergency. Now the interceptor craft's ascent must be direct, with no parking orbit. Trajectory and the time of launch must be still more precise. The spaceship in distress, although friendly, may no longer be able to cooperate and so the rescue craft's radars must be still more sensitive and with still higher transmitter power, and with still larger antenna systems for still greater sensitivity.

If a friendly although uncooperative spaceship presents such problems for rendezvous, how much greater will these be when rendezvous is with a hostile spacecraft? Its orbit will have been as secret as possible, and even this may change through the craft's ability to maneuver in order to confuse. Instead of carrying transponders and reflectors it will be as "dark" and silent as possible. It may even be constructed to present the smallest possible radar target. Here the interceptor is even more dependent upon electronics for his mission's success. Ground radar and computer direct him to within some twenty miles of the hostile target, and still more powerful and sensitive radar with virtually instantaneous computer aboard bring him, with his superior capability to maneuver, to target.

In all these manned rendezvous missions there are the

Electronics, Key to Exploring Space

same three kinds of control and guidance systems: the ground's tracking and data processing, and command link to the vehicle; the control and navigation systems within the vehicle itself; and the pilot—the man.

16

It Looks Easy . . .

Electronic communication provides the invisible link between Earth and spacecraft, between spacecraft and Earth. From one goes the command, the intelligence, which directs the mission to its success; from the other come the fruits of that success—meaningful new information, intelligence from space. This invisible link is a wave of electromagnetic energy stretching out through millions of miles of space, shaped in ways which a receiver will decode into the intelligence it represents. Strong though it is in some respects, it nevertheless also is so very tenuous—so very subject to destruction, to failure, to error, to loss, to distortion. And without it the mission becomes almost meaningless.

Design Problems

The problems that pop up in a communications link

make their appearance as early as in the designing of it. Just the spacecraft's part of that link presents endless problems to be solved, for instance. At first, it looks easy—just design the craft's telecommunications system so that it will transmit the signal for the required range. If this is to be a Mars probe, that distance might reach as far as 100,000,000 miles. But that should be no great problem. . . .

Of course, it is necessary that the signal be loud and clear and with the least background noise when it is received on Earth. Range is not the sole concern. There are other concerns: small size and light weight. In a spacecraft, every square inch and every ounce are valuable. And in this spacecraft there are experiments and equipments vying for precious space and weight allotments.

And what space finally is allotted to the telecommunications system may turn out to be irregularly shaped—another restriction on the designer of that system.

Perhaps the designer seeks to work around these conditions which are closing in on him by redesigning the system's antenna so that it will do more of the work required of the entire system.

But here, too, he may run into complications. The antenna must fit under the vehicle's nose cone, for launch. Even when folded up for this purpose, it is quite possible for the antenna to be still too large—and yet its

new requirements make this new, large size necessary.

(Perhaps at this point the designer privately dreams of a globe-girdling band of ground stations, each with receiving equipment so powerful that his design problems of transmission shrink to nothing. But this would be only a dream—a very expensive one from which taxpayers would be quick to awaken him.)

Sometimes the antenna problem can be solved by moving the antenna's location so that it will fit, after all, within the rocket's nose cone. But just as likely this solution brings a new problem with it—in its new location, the antenna may be blocked from Earth by the solar panels when the spacecraft at last is in flight. Reducing the size of the panels to overcome this is no real solution, for that would reduce the power supply for the system and thus probably complicate the problem with the antenna.

Hinging the antenna so that it can swing into a transmitting position *when needed* is a solution which works. Unfortunately, there is a cost: it takes weight and space and power supply for the electric motor which, upon command, does the swinging of the hinged antenna.

The problem twists and turns, almost as if it were eluding solution. Yet a solution—and a *good* one—must be found. It is to the credit of these persistent, resourceful, knowledgeable designers that such a solution finally is found, put to work, and proven successful.

Power-Distance Requirements

Power is precious and not easily come by. If batteries are to be the power source, the problem increases greatly as the distance increases between Earth and spacecraft. Being close to Earth, as the early Explorer satellites were, and transmitting fairly simple data for only a few days, requires merely dry cell batteries with .01 watt of power. Pioneer IV's batteries, however, were designed for transmission from a distance of some 700,000 miles. Its batteries had .18 watts transmitted power.

But deep-space distances compound the power-for-communications problem. The rule for figuring power requirements is this: the requirement increases as the square of this distance. This means that if you want communications for a probe going ten times farther than Explorer IV did, it will need one hundred times as much power. Explorer's .18 watts for 700,000 miles now becomes not 1.8 watts but 18. watts for the new distance of 7,000,000 miles.

Once every twenty-two months Mars approaches Earth to within 40,000,000 miles. This is almost six times the 7,000,000 mile distance which requires 18 watts of power. But that "almost six" is squared; it becomes some thirty-three times as much power: 600 watts. There is something else, too: the length of time these batteries must work. As distance increases, so does the time in flight. Time once figured in days now

must be figured in months. And is TV part of the instrumentation? Then very greatly increase your power requirements, for much more power is needed to transmit the "much more" electronic signals of a TV picture in comparison with a single instrument's simple "beep."

Space Damage

Solar cells furnish electric power for some types of spacecraft. These small, rather fragile cells are arranged on panels. The panels extend widely from the spacecraft and thus are targets for micrometeorites. A glass coating gives some protection but perhaps even that would wear away during extended space flights to come. A greater source of damage to these cells comes from radiation. Formerly a radiation shielding of quartz or sapphire some ten to thirty mils thick was used. This now seems to be less effective than revising the chemical composition of solar cells to make them radiation resistant.

Electric components within the spacecraft, although shielded from micrometeorites, are nevertheless subject to this high energy radiation damage. A transistor was exposed to the type of radiation encountered in the inner Van Allen belt. In only twenty-five days it had lost two-thirds of its output. This damage was caused by the effects of radiation, not by any solid. It is estimated that there is only a handful of matter in the entire Van Allen belt. Yet so powerful is the radiation here that manned

space flight probably will have to avoid passing through it.

Reliability

We take it for granted that the instruments and components and systems aboard the spacecraft will work without fail. Yet these are subjected to strains and vibrations at launch, to space's cold, radiation, magnetic fields, and micrometeorites during flight, and then again to strains and vibrations and probably great heat also as the spacecraft plunges into the atmosphere of the target planet.

Unattended, a TV-equipped moon probe speeds toward its objective and prepares to transmit pictures of future landing sites, commanded by a "Go!" radioed from Earth. What of all the effort and expense and hopes which went into the design and construction and launch and tracking of the probe, if the protective cap covering the telescopic lens of the camera has become stuck in place and refuses to budge?

Attitude

Some spacecrafts' missions require them to "tumble" in flight so that they view widely through an assigned area. Others rotate. Still others remain fixed in attitude so that their directional antennas point Earthward, save

power while transmitting strongest and clearest, receive commands without the distortion that might result in erroneous response. Unless these craft take the attitude assigned to them, their sensing and telemetering and command reception lose value. The value of the mission's results is diminished, sometimes very greatly.

Radio Interference

Even if all goes well, a great thief of transmitted intelligence often creeps into these telecommunications, especially when distance increases between Earth and spacecraft. It is radio interference. This garbler of radio signals can interfere as far away as still-unknown areas in space or right within the spacecraft itself. From the distant areas and from some stars come naturally caused radio noises. And within the spacecraft are electronic instruments which by their operation may be generating radio noise. Their power supply, too, may be a source of radio noise.

Training on the spacecraft are the great antennas at Earth tracking stations, and even Earth's warmth may be causing noise which the back lobes of these antennas pick up, augmenting the noise coming from space. Commands come from Earth antennas; radio noise often comes along, generated within the radio frequency system. Communication with the astronaut in a spaceship re-entering Earth's atmosphere is cut off during those

Electronics, Key to Exploring Space

few vital minutes; blanketing the vehicle is a plasma sheath created by the intense heat of speeding ship plunging into dense atmosphere.

Distance-Time

Communication over truly astronomical distances of space will present still another problem, the inordinate length of time between transmitting a signal and receiving its reply. Even though the signal travels at 186,000 miles per second, distances are so great that years will pass before this signal could be received and its reply returned to Earth. Alpha Centauri is Earth's nearest star system neighbor; nine years is required for a prompt exchange of intelligence.

Frequency Shortage

If two transmitters are within radio range of the same receiver, and if they are broadcasting on the same frequency, their broadcasts will interfere with each other or the stronger will drown out the weaker. "Jamming" is the technique of intentionally broadcasting noise on the frequency of the transmission which is to be garbled. Usually, however, every effort is made to prevent unintentional interference.

In this country, the Federal Communications Commission assigns each commercial, private and scientific

station its own radio frequency on which to transmit. The transmitters of spacecraft are included. But now, with so many transmitters, there is already a shortage of frequencies for assigning new transmitters. As for spacecraft transmitters, there are also those of other nations and with more still to come.

Power-Time

Power requirements increase not only with distance but also with length of time that they are to work. Vanguard I has surprised the world by continuing to transmit information for years after it was launched. Grapefruit-size, almost primitive compared with its sophisticated larger descendants, its transmitter is battery powered. If this early little spacecraft can do so well in continuing to transmit, why is there such a problem in powering later, better ones?

The answer is, how much more are you asking of these newer spacecraft? Vanguard and its cheerful chirping is close to Earth. It has only a few very simple experiments to report, and needs little power for transmitting these data as it passes close over a whole series of Mini-track stations around the world, reading-out to them with a minimum of interference. But now there are communications satellites and navigation satellites; hopefully, these will do their work for at least five years, possibly ten. And manned Project Apollo, though

Electronics, Key to Exploring Space

planned for only a two-week mission to the Moon, will need some two or three *thousand* watts of power for its systems in that short time.

And how much more energy is required to radio information from the Moon than from Vanguard? The answer shrinks by comparison with how much more energy it takes to radio information from Mars than from the Moon: about 40,000 times more. Electrical power requirements increase greatly as the scope of newer spacecraft increases in distance, duration of flight, the number of scientific instruments aboard, the equipment which processes their data, stores it, transmits it or—still more energy-consuming—televises it.

Problem Solving

Solar Panels

The newer spacecraft would require tons of batteries to meet their power requirements if it were not for other ways recently found for supplying that electrical power. One is the solar panel. A wealth of electromagnetic energy radiated from the Sun is streaming through interplanetary space of our solar system where space exploration will continue for years to come. Why not capture enough of that energy to meet a spacecraft's power needs? Solar panels do. Some are made of thousands of small photovoltaic converters, better known as "solar cells." These convert energy of sunlight into electric power. Saying it more simply than it is, an electron absorbs the energy of a photon. Some thirty thousand of these cells in a solar array will produce one kilowatt.

Electronics, Key to Exploring Space

That array will cover an area of about one hundred square feet and will weigh about one hundred pounds.

Instead of directly connecting the solar array to the instruments, there is a battery between. Approximately half of each orbit of an Earth satellite is in Earth's shadow, away from sunlight. Yet power is available to the satellite's instruments during that time because of a battery aboard. There is no danger of overcharging the battery: its charging rate is monitored on the ground from where a command can be sent to the battery's switch which cuts off the panels' flow of electricity. Undercharging, on the other hand, is automatically controlled on board: a control there cuts out the transmitter to save power for the receiver so that it still can receive commands from Earth.

Coding

Coding of signals—perhaps of concern more to the military—prevents their imitation or comprehension by others. This insures that a true command or a correct set of information passes between spacecraft and Earth. A kind of electronic "lock" in the receiving equipment accepts only those signals which are coded to fit that lock. But since interference may alter a command signal and so make it unacceptable to the lock in the receiver, it is necessary to make sure these kinds of interferences are "designed out" of the command link system. This

means working principally with the ground equipment where fortunately there are not the power and weight and size limitations imposed upon spacecraft equipment.

Frequency Shortage

Part of the solution to the problem of frequency shortages is in raising frequencies still higher in the electromagnetic spectrum. Proposed frequencies for communications satellites are in the $3.7 = 4.29$ gigacycle and $5.925 = 8.4$ gigacycle range. (A gigacycle is one thousand million cycles per second.) Producing such high frequencies presents difficulties. These are not only in design and manufacture but also in their results: when frequencies begin to approach those of light (which these don't do quite yet) they often are affected or distorted by rain, much as infrared rays are blocked by moisture.

Developing new frequencies and assigning these is not enough. There must be monitoring stations of the Federal Communications Commission. These will seek out unauthorized stations using frequencies belonging to space communicators. The monitoring stations will do this work by using high-gain directional antennas, sensitive receivers, and automatic frequency scanning devices.

As for international control of frequencies, it is yet to receive full agreement.

Relay

When communications distances become very great, perhaps the problems such distances create will be reduced by establishing relay stations in the space between. Even only one station, possibly located on the Moon or elsewhere in space, would serve to receive and strengthen those weak signals transmitted by a very distant spacecraft. Then it could retransmit these to Earth where they will be received clearly.

This technique is used now in cross-country communication. A line of microwave towers carries signals as weak as a flashlight's from one side of the country to another. Each tower is no farther than thirty miles from the other. If it were it would be beyond line-of-sight, and these signals are almost line-of-sight because their frequencies are so high. The whole relay is so fast it is almost instantaneous. At the end of the line, the signal is separated into its many telephone conversations.

If our present communications satellites are indeed virtually relay towers in the sky, their relay function should be adaptable to this new direction, toward space. Probably relay satellites will be functioning before a Moon relay station can be established.

The Laser

Something truly new is being developed for electronic communications. It is the laser. Its function is to treat light so that light's waves of electromagnetic energy can be modulated, as radio waves are modulated, to carry intelligence.

Laser is an acronym for Light Amplification through Stimulated Electromagnetic Radiation. This refers to optical frequencies (light) but sometimes the name is used interchangeably with "maser" whose first letter M refers to Microwave frequencies (radio). When the microwave region of the electromagnetic spectrum is passed and the infrared and visible regions are reached, a maser has become an optical maser, or laser.

Light has not worked as well as has radio in the communicating of intelligence. This is because only radio's waves are orderly and measurable and predictable. They can be worked with, modulated, and made to serve a purpose. But light, it will be recalled, is a mix of colors. Each color has its own frequency and wavelength. These strive with one another when they are mixed together in "light." This continual interference produces the "incoherence" of light. Radio waves, which are manageable, are "coherent." The function of the laser is to change the "incoherent" characteristic of light into the "coherent" characteristic of radio waves. (This is why the laser's light is called "coherent light.") When light

is coherent it has become manageable; it can be modulated, can be made to carry intelligence. And because frequencies of light are millions of times higher than radio frequencies, the quantities of intelligence which these can service are immensely greater than the capacity of radio frequencies.

The structure and operation of the laser is simple. This in itself is a problem eliminator. The laser is a solid-state device. It has no moving parts, no series of delicately interfitted components. It does the work of energy converter, oscillator, and antenna. Its principal part is a rod. Thus far a synthetic ruby rod has worked best. The rod is only some six inches long and three-quarters of an inch in diameter. It is cooled cryogenically; that is, it is enclosed in liquid helium which lowers its temperature to minus 456° F., almost absolute zero. At that extremely low temperature there is very little movement by molecules; this ruby amplifier generates no noise in the electrical signal it is producing. There is thus virtually no noise in the signal-to-noise ratio.

To power a laser is to "pump" it. Xenon gas tube lamps perform this function at present; perhaps later it will be done by the Sun, especially for lasers operating in space. The light source pumps up the energy level of the atoms in the ruby rod. But the energy level of these atoms varies. Sometimes it is high, a moment later it is low. When its energy level drops, that energy-amplified

atom loses this energy. And as it does, it gives it off—a bit of energy—in waves. Here in the laser the wave that is given off is a light wave. Red. Single wave length. Single frequency.

From a laser set up in the Lincoln Laboratory of M.I.T., thirteen bursts of light were shot at the Moon. Each burst lasted about one two-thousandths of a second. These hit the Moon and returned two-and-a-half seconds and a half-million miles later. When each burst was transmitted it contained some two hundred billion trillion photons of light. Only about twelve survived the round trip and entered the receiving telescope. But they arrived. And they were focused and amplified. They forged a new link with an object in space.

In its application to space use, the laser seems to be almost unlimited. Its coherence means that its beam can be directed as a flashlight's beam is directed. But here is a difference: the laser can keep that beam so tightly focused that a flashlight-width beam would arrive still spotlighted one hundred miles distant. The beam remains a straight, tight beam as it travels through space, ideal for line-of-sight space communications and tracking and beam-riding.

Laser can produce high performance radar. Military surveillance systems could grow out of laser's capability. And perhaps laser's high intensity beams are beams that some day may destroy hostile missiles and spacecraft, or supply power to a friendly craft. So intense is this beam

that it will penetrate the ion sheath generated around the hull of a spaceship plunging back into a dense atmosphere, bringing communication to the men inside.

The Diode

The ruby red of the laser's beam—red only at present, but other colors are being experimented with—may be matched by an infrared, invisible light beam which will carry radio and video intelligence, too. A new kind of diode, rather like a transistor but only the size of a pin-head, changes the electrical signal sent to it into a powerful beam of infrared light that can carry twenty thousand telephone conversations over line-of-sight distances. It, too, can penetrate the ion plasma sheath of a re-entering space capsule.

Re-entry tests show that the communication blackout takes place from an altitude of some 300,000 feet down to 75,000 feet. Tests also seem to show that extremely high frequencies should be able to penetrate this sheath, that 35,000 million cycles per second makes enough difference to be noteworthy; that 70,000 million cycles per second is much better; but that it may take as many as 300,000 million cycles per second to properly establish two-way communication with a re-entering space capsule—well within the capabilities of the laser and the diode.

Reliability

Reliability is the quality which is built into the instruments and devices and sub-systems of a spacecraft so that they will function throughout the mission. The assurance that they will comes from more than guesswork, from even more than mathematically calculating the probabilities of success for the mission. It seems to come more from remembering during each stage in the development of equipment, from idea and sketch to actual use in space where it is "on its own," that it must function reliably. The missions to follow-on after a Mars mission requiring months of travel are those which will include two- or three-year flights to the intermediate distance planets, Jupiter and Saturn. Their environment is hostile to these missions' equipments, yet these must function.

Quality is only part of the answer to the problem of reliability, as also is good design of the equipment. Another part is redundancy, the practice of "backing up" some part of your mission's equipment with an alternate set of the same kind. This is most often done when there is knowledge of too large a chance for failure even though the equipment's design and quality are good.

Still another approach to failure of electronic equipment is, oddly enough, the designing of these equipments so that they *will* fail—but at a time when you can anticipate it and so provide for it rather than being

Electronics, Key to Exploring Space

obliged to suffer unanticipated failure. This kind of design, say those who propose designing for failure, is simpler than designing for no failure throughout the time the spacecraft is in flight.

Achievement

A factor which contributes immeasurably to the solution of problems in exploring space is the sense of achievement which men enjoy when the seeds of new knowledge are telemetered by their distant spacecraft. Those responsible for gaining that new knowledge, truly a "first," feel a quiet but very deep satisfaction not just for what *they* did, but also for what their country has achieved.

New Approaches to Old Problems

The deeper into space the search penetrates, and the more data these penetrations report, the greater grow the problems of how to maintain communication and how to handle the volumes of data it brings. Perhaps more than just refinements or improvements in techniques and equipment is needed. Nor may it be enough merely to furnish more and more power for the spacecraft's electrical systems or to increase the signal-to-noise ratio by still finer design. Certainly it helps to know that the average rate of these noises can be predicted; this can be taken into account when designing the communication system. Perhaps the new strains soon to be put on the communication system by distance and data require a second look at the whole concept of the system. What can be done to approach it from a new direction, to reduce or even eliminate these problems of power and data handling and time and accuracy?

Computer

One approach may be in the functioning of the spacecraft's computer—to increase its capability. Unfortunately, its size and weight would have been increased correspondingly too, except for miniaturization. This is the continuing study and development of making electronic gear such as this still smaller, still lighter in weight, still less in its power demands.

When miniaturization permits, the spacecraft's computer will do more work without penalties of size and weight and power needs. That extra work will be with the data coming from the encoder. If the computer reduces that data before giving it to the transmitter, there is less work for the transmitter to do. And the transmitter is a great user of power, especially at interplanetary distances. At present the amount of data is growing fast. Explorer XII transmitted 350 binary digits per second, and in three months its ground stations had received about 6,000 reels of magnetic tape. But later spacecraft with improved transmission will be able to send as many as 64,000 binary digits per second.

Saving Time and Work

Increasing the efficiency of sending data from spacecraft is desirable, but it also creates new problems. One is to keep this greater deluge of data from swamping the

Earth computer operation. Another problem is one of time—how to get this information quickly to the scientist who requested it. If this can be done while the spacecraft is still in flight, perhaps the data may indicate that the scientist should command the spacecraft to further the experiment, by maneuver or by different use of the instruments aboard. When this is done, the value of the experiment often is greatly increased. And it saves the time and expense of building and flying a continuation of this experiment aboard a new spacecraft.

The problem of such great quantities of data originates in the spacecraft. If the spacecraft's computer can be constructed to translate raw data into a form that permits it to be fed *directly* into the Earth computer, a very great amount of time and work will be saved the Earth computer operation.

Interest in Only the Exceptional

Another possible solution is in having the spacecraft's computer constructed so that of all the sensor information fed into it, it is concerned with only the important or exceptional information. Why, for example, should it encode and telemeter temperature readings almost continuously, when these change only very little? Yet suppose that a sudden, marked change in these temperature readings is reported to the spacecraft's computer. Here is a condition which should be reported to Earth: it

Electronics, Key to Exploring Space

might warrant investigating. To accomplish this, the computer—on its own—notices the marked change in temperature and commands that it be relayed to Earth. In its ability to act on its own when an exceptional condition is presented thus, the computer is “self-adaptive.”

One method the spacecraft's computer can use to accomplish this is to measure the electromagnetic energy value of each sample coming from each sensor. If that value does not differ from a sample taken just previously—at least by an amount set into the system earlier—then the signal is not sent to the transmitter. But if the new sample's value does differ by that amount, or more, then it is sent on for transmission to Earth.

The amount for comparing these differences can, itself, be changed while the spacecraft is in flight—by radio command.

Manned Spacecraft Rendezvous

Astronauts in a manned spacecraft rendezvous—a critical operation—need flight information that is accurate, complete, immediate, and which they can comprehend at a glance. The new system of “interest in only the exceptional” presents their necessary flight information on just one picture tube.

If there is a significant change in each reported condition, or in the rate of change, or in the total effects of that change, then that exceptional condition is to be

brought to the attention of the astronauts. In so critical an operation as rendezvous, their principal interest is in conditions that are changing, especially those whose effects will be sudden or great.

Almost instantly, a computer-like instrument called a data processor produces this needed information. When the unusual condition is presented to it, it searches its stored programs. Among them it finds the correct information which corresponds to the condition. Then it presents that information on the face of the tube, a cathode ray tube. There it shows the circumstances of this special condition, the facts associated with the condition (which help the astronauts decide what to do about it), and the calculated probabilities of what will happen as a result of the new condition.

This computer system takes no action; it makes no decision. These are the responsibilities of men. But it does give the astronauts the information they need for decision and action, and it does this clearly, promptly and accurately.

Power Sources

Chemical systems for powering spacecraft equipment include the battery, one of several chemical sources of power. Another such source is the fuel cell. Lighter in weight and more efficient, this newer kind of battery has no electrodes. Instead, its chemical reactants which pro-

duce electricity are stored in tanks outside the cell where they feed into the cell as needed. The greater the tanks' capacity, the longer the cell's operating life. Fuel cells are proving so successful they may eventually replace the present cadmium nickel battery.

Sun-powered systems furnish electrical energy for spacecraft equipment, too. Since it is the Sun which continually gives these systems their power, they are better suited to long flights than are batteries limited by their supply of chemicals. Of these Sun-powered systems, the solar cell is the most familiar. Less familiar is the solar thermionic power system. This employs a large mirror to focus solar energy and so cause electrons to behave very like electrons at work in a radio tube.

Nuclear systems provide the third kind of power supply for spacecraft equipment. One of the better known of these nuclear power suppliers is the Snap 8. This may be the type of system that will furnish wattage for the high-power communications satellites. It functions very much as a steam turbine does when it drives a generator to make electricity. However, instead of steam from water heated by coal or fuel oil, Snap 8 boils a mercury fluid by heat from uranium fissioned in the nuclear reactor. A condenser returns the vapor to a fluid ready to undergo the cycle again, just as happens in the steam system. Snap 8's reactor-and-turboelectric system should produce between 30,000 and 60,000 watts of power.

Applications of New Knowledge

Electric Propulsion

It is only a step from the electrical power systems used inside the spacecraft to electrical power systems for propulsion of the rocket. Rocket propulsion systems would need not kilowatts but megawatts—millions of watts. But perhaps Snap 8 may resemble the system which eventually will do that job. Today's rockets furnish their thrust by burning a chemical fuel which expands and forces its way from the combustion chamber and out of the rocket via a small nozzle at the rocket's tail.

Electrical propulsion also employs a rocket-type engine and also achieves thrust by exhausting a gaseous propellant. But it is one of plasma rather than of the hot gases produced by burning chemicals. There are some

Electronics, Key to Exploring Space

three systems of electric propulsion: arc jet, plasma jet and ion engine. None of these three types of engines is capable yet of generating sufficient thrust to lift a vehicle off the ground and put it into space. For the present, this must continue to be done by boosters fueled with chemicals. But once in space, perhaps in parking orbit some 300 miles out, a nuclear-electric spacecraft could separate from its chemical booster and then begin the electrically propelled phase of its flight. In space, where the rocket meets no resistance to its flight, the weaker thrust of electric propulsion is, nevertheless, sufficient. When that thrust is applied continually, the rocket's velocity continues to increase. And so, long-range flights will have their time of flight considerably shortened; the greater the distance, the greater will be the increase in velocity. This desirable condition is also practical because the fuel requirements of electric propulsion systems are very modest. Fortunately, too, these systems' mechanisms are simple and lightweight.

Other Applications

Already some of the fruits of space exploration are at work benefitting us or are planned in detail and almost ready. And at the same time these are serving as research tools for further knowledge both in improving their own capabilities as well as in gaining new knowledge.

Tiros, the satellite weather forecaster, has proved itself well, and has also served as the basis for its follow-on, Nimbus. And Nimbus may, in the same manner, give way to *its* proposed follow-on, the "stationary" Synchronous Meteorological Satellite (SMS).

Telstar and Relay and Syncom, all satellite communications systems, also have proven themselves, also are furnishing the groundwork information for future satellite communications systems that will be commercially usable and profitable. Navigation satellites will evolve from the present Transit series, whose results have exceeded hopes for them. Soon satellites will receive telemetered reports from unattended sensors placed around Earth's lonely spots—mid-ocean or mountain tops or mid-desert. Not only will their information be of scientific interest but it also will aid sailors and fishermen and fliers and weather men.

More of these benefits will come as space computers talk to Earth computers and as men learn to use more and better information codes and symbols and signs in their communication with machines. Millions of conversations, carried on a beam of coherent light, may give way in part to bursts of high-speed digital or other code communication from one machine to another.

These are only a few—a very few—of the fruits of that great search in space. These are benefits for everyday use. But everyday benefits surely do not provide the

sole reason for that search for knowledge; these aids to our better daily living are not a terminal product of that great effort in space. Rather, they are way-stations.

Even while we use these newly gained results, we study them. We learn more of their functioning, their characteristics, their individual components. And this new information is put to use by the scientist and the engineer as they design still newer tools for the search: satellites for gaining solar, geophysical and astronomical information; probes and fly-by's and unmanned landings on other-world surfaces; investigations of interplanetary space and, later, of the space out of the familiar plane in which our planets wheel.

Some day, perhaps fairly soon, a man will stand on another world's soil and examine it, and examine the strange sky overhead. For it is there, rather than close to Earth, that man can contribute so much in the search of space. He, a compact combination of sensors and self-adaptive, decision-making computer, far surpasses the products of his own manufacture which he designed for this work.

But now, for the time being, it is without his presence millions of miles out in the lightless silence of still strange space that unformed information continues to be discovered by sensors, converted into electrical energy and sent to a spacecraft's encoder which translates it. As electromagnetic energy, in its new form of bits, this

intelligence is flung by the transmitter across the void in the direction of Earth. There giant antennas, tracking silently and ceaselessly, capture that faint signal of electromagnetic energy whose modulation of intelligence has remained the same all through those millions of miles. Led into the radio's receiver, that weak signal is instantly vitalized by fresh reserves of electrical energy. Then decoded, it is fed into an electronic computer that works it over and over until it becomes new, distinguishable, usable and useful scientific information. Fed back, perhaps in a different form, to the vast reaches of space, still newer knowledge results—knowledge for use in the search on Earth and the search in space.

This is intelligence which will be utilized in man's effort to understand himself and his Universe. He seeks, and learns—on Earth and in space. And so the spiral goes—always upward. Man is truly reaching for the stars.

The spaceship settles gently on the strange surface of another planet. Its astronauts have negotiated their descent successfully. Information coming from them and from their craft's sensors is utilized to insure the success and even greater safety of many more descents by those who will follow. Now landed and beginning their work of exploration, these scientist-astronauts televise and radio new and more precise information to Moon Base

Electronics, Key to Exploring Space

and to Earth. This is information of greater value than any that has come from other worlds before, for this is information sensed and evaluated not only by instruments, but by man himself.

Appendix

Spacecraft which are themselves the subject of study, for the purpose of evolving better spacecraft, are termed developmental rather than operational. They are truly developmental even if they are at work, gaining new scientific knowledge or relaying communications or photographing Earth's cloud cover from above or providing ships with navigational position information.

The criterion for designation seems to be: a satellite system is operational if it produces the results expected of it, *each time* it is used, and it is used on a regularly scheduled basis. If this is so, then our communications satellites and our navigational satellites and our weather satellites are at present developmental, not operational.

COMMUNICATIONS SATELLITES

There is the Passive Reflector type and the Active Repeater type with variations within each. Which one is best? The answer has not appeared yet.

Appendix

The Passive Reflector

Echo I, the 100-foot diameter balloon, has worked well in reflecting signals beamed against it. Although referred to as a kind of mirror, it might be even more accurate to compare it with the shiny decorative ball one frequently sees in gardens, mounted atop a base often used for bird-baths or sundials, catching and reflecting the sun's rays no matter from which direction they come.

Echo II, 135 feet in diameter, will have its skin stretched still tighter by the gas which inflates it after it is lofted into orbit. This, plus reinforcing its skin with an inner and outer coating of aluminum laminate, should cause its skin to remain smoother and therefore be a better reflecting surface than was Echo I's, whose wrinkling somewhat reduced its effectiveness.

"Rebound" is a current study to determine how best to launch three of these passive type spheres from a single satellite, each to be equidistant from the other and at an altitude of some 1,700 miles—a height not sufficient to permit world-wide coverage.

The Active Repeater

Telstar is perhaps the best known of this type, although NASA's Relay has achieved a longer operating record. They are not identical spacecraft, however, for each has its own configuration and each differs from the other in a number of ways. But both operate by receiving a signal from the ground, amplifying it, and then retransmitting it on another frequency.

Telstar is a satellite whose diameter is slightly less than one yard. Its orbit was planned for 600 to 3,500 miles—high enough to relay messages between continents. Solar cells, sapphire-coated to protect against radiation, transform sunlight into electrical current that is stored by a nickel cad-

mium battery for use by the telemetry system. A corkscrew antenna atop the satellite is used for command and telemetry as well as to supply a tracking signal. But the antennas which receive and transmit the communications are located around the satellite's middle, and so are termed "equatorial." They, too, transmit a tracking signal. One more tracking signal is supplied: three of the satellite's 72 flat facets which cover it are reflectors of sunlight and thereby are tiny beacons by which optical-tracking telescopes on Earth can follow this satellite's course.

At Andover, Maine, the principal U.S. ground station transmits its signals to the satellite on a frequency of 6390 megacycles. The satellite amplifies these by a factor of 10,000,000,000, in steps, using fourteen germanium transistors and one foot-long tube which is a traveling-wave tube amplifier. Then the satellite rebroadcasts these signals on a frequency of 4170 megacycles. These signals can represent voice, television, or photos. The difference between the two frequencies is sufficient to prevent their being confused with each other. This also is true of the satellite's other frequencies: 136 mc. for telemetry, 120 mc. for command, and 4080 mc. for tracking. Bell Telephone Laboratories and American Telephone and Telegraph Company are sponsors of Telstar I, in cooperation with NASA. Telstar II is better designed against radiation damage.

Relay I is NASA's communications satellite, launched later than Telstar I. Its purpose, like Telstar's, has been to show how to better design its successor: here, principally in the areas of solar cells, batteries, connectors and the traveling-wave tube. Relay's control net includes stations identified as COMSOC (Communications Spacecraft Operations Center, the Net's control point) at NASA's Goddard Space Flight Center in Greenbelt, Maryland; and the communications stations of COMAND at Andover, Maine, where AT&T's antenna is located; COMHIL at Goonhilly,

Appendix

on the Cornish Peninsula, Britain; COMBOD at Pleumeur-Bodou, Brittany, France; COMTEL, operated by Tele-spazio, Fucino, near Rome, Italy; COMNUT at Nutley, New Jersey, which is operated by the Federal Laboratories Division of International Telephone and Telegraph Corporation; COMRIO, with whom it is linked, in Rio de Janeiro, Brazil; and more countries soon to be added.

Relay I is equipped to accommodate television, two-way telephone, teletype and data experiments. Its height is 33 inches; its girth, about 29 inches. Like Telstar, it uses solar cells and nickel cadmium storage batteries. It carries two transponders (for redundancy). Also for redundancy is the doubling up in its telemetry and command equipment: two command receivers, two subcarrier demodulators, two command decoders, two telemetry transmitters, (and one command control unit, one telemetry encoder, and one antenna). Minitrack "watches" Relay's 136 mc. beacon and thus tells the communications stations where their antennas should "look" for Relay.

One of Relay I's most interesting and hopeful experiments occurred in April, 1963: transmission of electroencephalograms—"brain waves"—from Bristol, England, to Minneapolis, Minnesota, where a computer reduced the data into printed form which served as the basis for making the diagnosis. Within one minute the interpretation had been made and was sent back to England.

Early active communications satellites contributed their share of information in this process of developing an operational satellite communications system. In 1958, Army's SCORE sent President Eisenhower's Christmas message from the "sky" to the world. In 1960, Army's COURIER received messages and stored them on tape, then retransmitted them when in "sight" of the next ground station along its orbit.

Active Synchronous Repeater

Project SYNCOM is an active repeater satellite which is to be placed in orbit at a velocity and altitude that will keep it synchronized with Earth's rotation, and so it will appear to "hover" in one spot above Earth. An advantage is that its ground stations thus require simpler antenna systems, since these will not have to "look" for a small satellite rushing up at them from over the horizon. Another advantage of the synchronous system would come into being if there were a few such synchronous satellites, equally distant from each other. They then would have almost the entire world in view and thus would be able to serve almost the entire world with communications.

SYNCOM I's orbit inclines from Earth's equatorial plane just enough to make it appear to weave a "figure 8" pattern across the equator as does SYNCOM II's orbit also. Later SYNCOMs may be truly "motionless" at their altitude of 22,300 miles. They also may have the ability to accommodate several transmissions sent simultaneously from the ground—to have a multiple access capability.

Satellite Directly to Home Receiver

This system, still in the future, will some day come to pass. (For the present, communications satellites will continue to have their signals picked up by specially equipped ground stations which greatly amplify these, then send them to broadcasting stations where they are transmitted in the normal manner.) The system requires highly directional space antennas which we do not yet know how to erect in space, and the ability which we do not yet have to stabilize a satellite so precisely that these antennas are directed truly precisely, and the knowledge, which we are still gaining, of

Appendix

how to generate on board the satellite those kilowatts of power that such a system would demand.

Project West Ford

Our military, always aware of their need for a jam-proof, non-destructible world-wide communications system, have been chiefly interested in the experiment known as Project West Ford. Seventy-five pounds of copper filaments, each half as thick as a human hair and only some seven-tenths of an inch long, are sufficient to girdle Earth with a belt five or ten miles wide and about thirty miles deep, at an altitude of several hundred miles. Each hairlike wire thus would be about a quarter-mile from the next nearest one. Yet each was to have acted as a kind of antenna, a dipole, in reflecting radio waves beamed there—reflecting best those whose length is twice the dipole's length. At this wave length, one pound of these wires would do better radio-wave scattering than did the 100-foot ECHO I. True, a powerful signal would need be sent, and a very weak one would be received; but with adequate facility on ground and on board, the signal would be sufficient for its purpose. And the system would be secure against hostile action.

It was judged that the only vulnerability was to sunlight whose pressure was calculated to limit the orbital lifetime of these dipoles to some seven years. The first attempt to orbit these needles failed when the package containing them failed to open and distribute them. Wide reaction against the project, particularly from astronomers, may have had an effect in delaying a subsequent attempt.

NAVIGATION SATELLITES

Transit is Navy's developmental program whose series of satellites has done well and also augurs well for an opera-

tional system of satellites for all-weather world-wide navigation. That system envisages four satellites, each in a particular orbit, which will furnish data for fixes of great accuracy not only to surface and sub-surface ships but also to aircraft. What kind of navigational system for space ships may evolve eventually from a series whose beginning was Transit, remains to be seen.

The first Transit, launched in 1960, demonstrated that the system as contemplated was feasible. Two months later, the second Transit was launched, and was a "first" for this country in that two satellites were lofted together and then separated after entering orbit. Transit III demonstrated by its memory system that data of its orbital path can successfully be transmitted to it and just as successfully be transmitted from it to aircraft or ships to use in obtaining their fixes. The fourth Transit was the first spacecraft to be equipped with a SNAP generator for powering two of this Transit's four radio transmitters. Transit V, launched in December 1962, continues the navigation experiments and points the way also to future navigation spacecraft design which probably will incorporate lighter weight payloads, nevertheless accomplishing as much or even more work.

Anna 1B is not quite a navigational satellite; rather, it is a geodetic satellite. It is designed to supplement navigational information by providing data to increase the accuracy of present information about Earth's gravitational field, the location of positions on Earth's surface in relation to Earth's center of mass, and the shape and size of Earth itself.

"Anna" is an acronym for Army, Navy, NASA, and Air Force—all directly interested in this type of information and in the craft itself. Solar cells power the flashing lights aboard this spacecraft by which it is photographed against a background of stars by stellar cameras located around the world. As experienced with other, earlier satellites, optical tracking

Appendix

makes possible a great accuracy; and the precision with which this satellite's position is determined has resulted in still greater accuracy of information—position-in-space information more precise than any obtained previously.

WEATHER SATELLITES

In working toward an operational meteorological satellite system, seven TIROS weather satellites have been launched thus far, and their follow-on, Nimbus, is soon to come. The Synchronous Meteorological Satellite (SMS), follow-on to Nimbus, already is under consideration. The chief differences in the activity of these three systems is that TIROS spins as a top does, so that its orientation is not always toward the Earth. Nimbus, however, is stabilized so that its cameras always view Earth. Although SMS is not yet very far in its planning, one current consideration is to keep it Earth-oriented, as Nimbus is, but with the addition that one of its cameras will take a wide view (perhaps as much as one-third of Earth's surface, because SMS will be high enough to be "stationary"), while a second camera will focus, upon command, on a particular area within the larger one where the meteorologist finds special interest at that time.

TIROS is the acronym for Television InfraRed Observation Satellite. Its name describes the principal equipment aboard this hat-box-shaped spacecraft: TV cameras, infrared sensors to learn the amount of energy reflected and re-radiated by Earth and its atmosphere, and to measure cloud cover at night. There also are tape recorders, timers, and the telemetry system of receiving and transmitting equipment and their supporting antenna and power equipment, and the spacecraft's own control equipment such as the spin-up rockets and the de-spin mechanism. Later TIROS also carry two additional sets of radiometers. One measures

a wider area than the other, for solar energy amounts, so as to determine the amount of solar energy which created the weather—and thus to learn how to better predict in longer range forecasting.

Commands set the timers which start the cameras when the satellite is over an area it is to examine. These specially developed cameras hold the picture temporarily on the tube while an electron beam converts it into a TV kind of signal. This is the signal which can be read-out directly to the ground station if the satellite is over it, or can be stored on magnetic tape for later read-out. The data acquisition stations are near Los Angeles and on Virginia's east coast, near Maryland, and at Fairbanks, Alaska. Meteorological data is most valuable if it is timely; the read-outs are analyzed and then transmitted to the National Meteorological Center and disseminated world-wide to meteorological services. Subsequent use of that information is made by meteorologists for climatological studies and other research.

Nimbus

For all its useful results, TIROS is a developmental, not essentially an operating, system. Nimbus is intended to be the first which is a direct lead-in to the National Operational Meteorological Satellite System (NOMSS). Nine of these satellites are scheduled for launching from 1964 through 1966. This Earth-oriented spacecraft will have greater coverage than TIROS, viewing cloud patterns almost completely around the world in daylight, and performing nighttime measurements of cloud cover through estimates of atmospheric and terrestrial radiation by radiation sensors on board. Real-time use will be made of Nimbus' data coming from the electrostatic tape cameras which produce continuous picture strips, from image-orthicon cameras for photographing clouds at night, from

Appendix

radar for detecting precipitation, and from spectrometers for measuring temperatures in the atmosphere and possibly also measuring distribution of water vapor in the atmosphere. Data acquisition stations are to be built in Alaska and Nova Scotia to accommodate the nearly polar orbit of this series of satellites. The communications net will connect to NASA's Goddard Space Flight Center in Maryland and to the Weather Bureau's Meteorological Satellite Activities Center in nearby Suitland. There the information, analyzed, will be matched with other weather data and promptly sent to weather stations here and overseas for use in weather forecasting.

In the development of new sensors, a search of the electromagnetic spectrum continues for regions related to the physics of the atmosphere: the ultraviolet, the microwave regions and the CO₂ absorption bands. Data handling for Nimbus will require much greater capacity than for TIROS; and the more timely that weather information may be, the more valuable it becomes.

SMS

This may be the satellite to be placed in an equatorial orbit at an altitude of 22,300 miles. If it is, it will appear to be stationary above a point on Earth. One of its two television cameras will view about one-third of Earth's surface except for the polar areas; the other television camera, directable, will provide a close-up picture of a limited area within the larger area—of a storm, for example, even as it moves across the face of Earth. Three SMS's, properly placed, would be able to view almost all of Earth's surface except, again, for the poles. If SMS is developed, it nevertheless may not necessarily replace Nimbus; rather, it might work in complement.

ORBITING OBSERVATORIES

In addition to the Orbiting Astronomical Observatory, there are the Orbiting Solar Observatory and several variations of the Orbiting Geophysical Observatory. All, for the present, are unmanned. High capacity data acquisition stations will serve these satellites as well as the Nimbus satellites, too.

Orbiting Solar Observatory

This series of satellites is to study the Sun and its phenomena by means of spectrometers, neutron flux sensors, and gamma ray monitors. Its orbit of some 300 miles above Earth requires ninety-five minutes for completion. Five of those minutes are used in the read-out of the tape recorder on which eight sub-carriers have been multiplexed. When OSO I encountered operating difficulties after eleven weeks of continuous operation, neither of its two tape recorders worked; only real-time information then was received. In the time prior, however, OSO observed twelve solar flares and several times that number of sub-flares. It furnished new and good information about these.

Orbiting Geophysical Observatory

Normally, this observatory's orbit is an almost circular one. But when it is launched into an eccentric orbit whose perigee is some 160 miles and apogee about 70,000 miles, it becomes known as EGO (Eccentric Geophysical Observatory). In an orbit of this description it can best study magnetic fields and energetic particles, plus other geophysical phenomena required by an orbit of that eccentricity.

OGO becomes POGO when placed in a Polar orbit for

Appendix

the principal purpose of studying the ionosphere and atmosphere over the north and south poles.

WHAT VENUS-PROBE MARINER II FOUND

This spacecraft's infrared and microwave radiometers reported a surface temperature that may be as hot as 800° F. (200 degrees hotter than needed to melt lead); very little carbon dioxide at cloud level which starts at about 45 miles up from Venus' surface and goes as high as 60 miles; and no break in the mass of clouds that appear to be composed of condensed hydrocarbons which resemble those contained in our smog. Mariner also discovered a mystery in the cold clouds: one spot some 20° F. colder than the remainder of the cover. This may be due to a mass of clouds higher or denser, or to some feature on Venus' surface that is hidden by these clouds.

At the 21,648-mile distance Mariner II flew past Venus, no magnetic field was discovered, nor were any increases in magnetic forces observed over those measured in interplanetary space while the spacecraft was en route. The magnetometer reported magnetic fields almost continually present in its path to Venus, although these fields were weak compared with Earth's.

The theory that the Sun's atmosphere may extend into interplanetary space in a diminished but nevertheless measurable form, and thus there is a kind of "atmosphere" of interplanetary space, seems to have been supported by Mariner II's findings. The solar wind is indeed very much present in interplanetary space. The blast of this hot electrified gas moves at speeds from 250 to 450 miles per second and at temperatures of some 1,000,000° F.

As for cosmic rays, Mariner's measurement of these would equal a dosage of three roentgens of radiation absorbed by

a man had he made that same trip—safe enough for a man over the four-month period which the trip took.

Another encouragement to manned space travel is in Mariner's report that only two tiny micrometeoroids impacted the spacecraft during its 1,700 hours of recorded flight time. There was no concentration of micrometeoroids around Venus, as there is around Earth—new information of interest in relation to the development of the Solar System.

Not all the benefits from Mariner II are "up." One "down" benefit is a result of tracking: the absolute location of the Goldstone station had been known to within 100 yards; but after Mariner's data have been completely analyzed, Goldstone's location will be known to within 20 yards. Exact measurements used in tracking and measuring cannot be exact if the location of the measurer is itself not exact.

And as for radio communications, Mariner II set a new world's record for range: 53,900,000 miles from Earth. The bits of information transmitted numbered 111,000,000.

Index

- Alpha Centauri, 132
- Antenna
 - DSIF, 117
 - interferometer, 118
 - phased array, 121
 - receiving, 66, 73, 83, 84
 - search via, 117
 - transmitting, 70, 81, 83, 84, 103
 - directional, 83, 103, 104, 131, 137
 - omnidirectional, 103, 104
- Apollo, 133
- Astronaut, 13, 101, 102, 111
- Atom, 9, 10, 30, 140-1
 - electron, 9, 10
 - hydrogen, 9, 13, 14, 15, 74
 - nucleus, 9, 10
 - protons, 60
- Attitude, 65, 108, 130-1
 - pitch, 65
 - roll, 65
 - yaw, 65
 - see also* Maneuver
- Baker-Nunn camera; *see* Tracking, optical
- Betelgeuse, 5, 8
- Bus; *see* Spacecraft
- Cathode ray tube, 85, 149
- Commands, radio, 66, 69, 91, 101, 102, 105, 106, 107, 108, 109, 116, 136
 - composition, 106
 - errors, 107
 - types, 102
 - via television, 109-110, 148
- Communications, 153
 - electronic, 21, 125
 - net, 119-120
 - radio, 10, 12, 30
 - radio relay, 138
 - satellite relay, 138, 153; *see also* Appendix
 - see also* Laser
- Computer, 3, 5, 16, 35, 36, 51, 52, 56, 65, 77, 87, 89, 90, 91, 92, 100, 101, 116, 120, 122, 123, 146, 147-8, 149
 - analog, 88
 - binary code, 80, 88, 89, 93, 94, 106
 - data processor, 149
 - digital, 87
 - encoder, 87, 93, 95
 - program, 90, 102
 - see also* Tracking

Index

- Corona, 33
Cygnus, 75
- Data processing, 124, 145, 146, 149
- Diode; *see* Infrared radiations
- Dust, cosmic, 8, 20, 27, 61, 70
- Earth, 4, 5, 7, 9, 11, 33, 111
 origin, 13, 20-21, 23, 76
- Earth-sensor, 103, 104; *see also*
 Photoelectric cell
- Electrical signals, 40, 85
- Electromagnetic energy, 4, 5, 6,
 8, 9, 10, 11, 14, 15, 17, 25,
 31, 32, 56, 57, 65, 72, 75,
 79, 80, 81, 82, 85, 86, 91,
 101, 103, 104, 106, 107,
 108, 112, 117, 135
 color, 14, 15, 32, 72, 82
 frequencies, 67, 73, 80, 81, 82,
 96, 113, 115, 140
 frequency shortage, 132, 137
 light, 85, 139
 radio waves, 14, 32, 73, 74, 79,
 80, 81, 82, 83, 84, 96, 139
 carrier, 95-6
 sub-carrier, 96
 radio waves from space, 74, 75
 spectrum, 15, 59, 68, 72, 80,
 82, 85
 wavelength, 32, 57, 72, 73, 80,
 81
 see also Commands; Laser;
 Voltages
- Electron, 80, 81, 84, 85, 88, 89,
 90, 135; *see also* Atom
- Element, 9, 33, 73
- Experiment, in-space, 46, 47, 48,
 49, 50, 51
- Explorer, 128, 146
- Extraterrestrial life, 10, 13, 15,
 16, 41, 42
 Carbon 14, 16
 carbon dioxide, 15, 16
- Federal Communications Com-
mission, 132, 137
- Frame; *see* Computer, Binary
 code
- Friendship 7, 43, 44
- Galaxy, 6, 7, 9, 75
- Gravity, 9
- Hydrogen, 73, 74, 75; *see also*
 Atom, hydrogen
- Hyperventilation, 97
- Hypoxia, 97
- Infrared radiation, 15, 41-2, 59,
 82
 communication via, 142
- Interception, manned, 121-124
- Interference, radio, 131-132
- Interferometer; *see* Antenna
- Interplanetary medium, 28, 29-
 30; *see also* Space, compo-
 sition
- Ionosphere, 30, 57
- Laser, 139-142
- Light, 5, 6, 10, 14, 32; *see also*
 Electromagnetic energy
- Lincoln Laboratory, M.I.T., 141
- Magnetic field, 29, 59, 74
- Magnetic tape, 40, 85, 87, 95, 97,
 102, 146
- Man, 3, 4, 13, 40, 42-3, 97-100
 body in space, 17, 18, 22, 24,
 43, 44
 function in space, 38, 42, 154
- Maneuver, mid-course, 65, 66, 90,
 91, 92, 116; *see also* Mar-
 iner; Ranger
- Mariner, 54-6, 102, 103, 113
 findings; *see* Appendix
 scientific experiments, 55, 56;
 see also Scientific instru-
 ments
- Mars, 8, 13, 15, 128
 moon Phobos, 8
- Maser; *see* Laser

- Mercury (planet), 55
- Mercury (Project), 101, 120; *see also* NASA
- Micrometeorites; *see* Dust, cosmic
- Milky Way; *see* Galaxy
- Miniaturization, 146
- Minitrack; *see* NASA, Earth Satellite Instrumentation Stations
- Mission, 40, 52, 55, 63, 86
 - experiments in space, 47-50, 54-56, 64, 92, 94
 - experiments on Moon, 71
 - fly-by, 63, 64
 - hard-land, 64
 - projects, 52, 53
 - soft-land, 64, 71
 - see also* Mariner; Ranger; Probes
- Modulation, radio
 - AM, FM, PM, 96
- Moon, 7, 20, 21, 23, 35, 66, 68, 70
- Moon-Crawler, 71
- Moonquakes, 70
- Multiplexing, 96
- National Aeronautics and Space Administration (NASA), 47, 49
 - Central Computing facility, 120
 - Deep Space Instrumentation Facility (DSIF); Deep Space Stations, 105, 117
 - Earth Satellite Instrumentation Stations, 105, 118
 - Goddard Space Flight Center, 48, 105, 120
 - Jet Propulsion Laboratory, 105
 - Life Sciences Division, 48
 - Minitrack, 118, 120, 121, 133
 - Project Mercury, 101, 120
 - control center, 105
 - Space Science Division, 47
- Nimbus, 153; *see also* Appendix
- North American Defense Space Detection and Tracking System, 121
- Orbiting Astronomical Observatory, 108, 117; *see also* Appendix: Orbiting Geophysical Observatory; Orbiting Solar Observatory
- Oscillator, 93, 140
- Payload (unmanned spacecraft); *see* Sensors
- Photoelectric cells, 108, 116; *see also* Earth-sensor
- Photon, 135, 141
- Photovoltaic converters (solar cells), 135
- PIAPACS, 99
- Pioneer, 128
- Power supply
 - for equipment, 83, 128
 - batteries, 83, 128, 135, 136
 - fuel cell, 149-150
 - nuclear, 150
 - solar cells, 129
 - sun-powered, 150
 - see also* Laser, 140, 141
 - for maneuver, 65
 - for rocket propulsion
 - chemical, 151
 - electrical, 152
- Prism, 14
 - grating, 32
- Probes, unmanned, 21, 35-6, 95
- Program; *see* Computer
- Project; *see* Apollo, Mariner, Mercury, Pioneer, Prospector, Ranger, Surveyor
- Prospector, 71
- Radar, 77, 84, 90, 92, 112, 121, 122, 123; *see also* Laser, 141; Tracking
- Radar astronomy, 76-78

Index

- Radiation, 8, 11
 cosmic, 27, 29, 60
 secondary, 40
 damage by, 129
 gamma rays, 68, 82
 radioisotope, 74
 ultraviolet, 24, 27
- Radio
 communication, 79, 103, 104
 receiver, 51, 74, 77
 telescope, 73; *see also* Radio astronomy
 waves; *see* Electromagnetic energy
 see also Antenna; Radar; Radar astronomy
- Radio astronomy, 73, 76, 78
- Radioisotope
 Carbon 14, 16
- Range (radar), 84, 115
- Ranger, 63, 64, 65, 66, 67, 68, 69, 71, 102, 103, 104
- Real-time, 102, 120
- Relay (communications satellite); *see* Appendix
- Relay (radio), 153
- Research
 directed, 52
 fundamental, 52
- Rockets, 34, 35
- Satellites (artificial), 34-5; *see also* Appendix: Communications satellites
- Scientific instruments
 cosmic dust detector, 41, 61
 gamma ray spectrometer, 67-8, 82
 Geiger-Mueller tubes, 60, 61
 infrared radiometer, 41, 58
 ion chamber, 60, 61
 magnetometer, 41, 59
 microwave radiometer, 39, 40, 56-7, 58
 radar altimeter, 68, 102
 seismometer, 69
- Scientific instruments (*con't.*)
 solar plasma detector, 41, 62
 television camera; *see* 41, 65
- Sensors (end instruments), 3, 4, 5, 10, 21, 39, 51, 86, 93, 100
 biosensors, 39, 43, 97-100
 (engineering instruments), 39, 44, 56, 94, 108
 analog, 94
 digital, 94
 see also Scientific instruments
- Snap 8, 150, 151
- Solar cells, 129; *see also* Photovoltaic converters; Solar panels
- Solar flare, 28-9, 74
- Solar panels, 61, 127; *see also* Photovoltaic converters
- Solar System, 5, 6, 7, 9
 origin, 13, 21
- Solar weather, 30
- Solar wind, 29
- Space, 3, 6, 8, 19, 30
 cislunar, 36
 composition, 46, 49
 interplanetary, 38
 manned exploration, 16, 17, 18, 19
- Spacecraft, 2, 3, 48, 49, 50, 63, 64
 operating equipment, 51
 see also Mariner; Ranger; Voyager
- Spectroscopy, 15, 72-3
 spectrograph, 41, 42
 spectroscope, 32, 33
 see also Prism
- Star tracker; *see* Photoelectric cell
- Stars, 4, 5, 6, 8, 9, 24
- Sun, 4, 5, 6, 7, 9, 10, 11, 13, 27, 33, 75
- Surveyor, 71
- Synchronous Meteorological Satellite, 153; *see also* Appendix
- Syncom, 153; *see also* Appendix

- Telecommunications system
 - designing, 126
- Telemetry, 3, 10, 21, 93, 100, 107
- Telescope, optical, 4, 5, 6
- Telescope, radio; *see* Radio, telescope; Radio astronomy
- Television, 16, 41, 65, 66, 67, 69, 84-5, 108
 - command; *see* Command
- Telstar, 153; *see also* Appendix
- Thermal Design Problem, 49
- Tiros, 153; *see also* Appendix
- Tonto, 64, 66-7, 69
- Tracking, electronic, 90, 91, 92, 111-119
 - data acquisition, 117-118
 - direction, angle of, 115-116
 - Doppler, 112-115, 116
 - range, 84, 115
 - stations; *see* NASA
 - transponder, 112, 114
 - see also* Laser, 141
- Tracking, optical, 119, 121; *see also* Baker-Nunn cameras
- Transit, 153; *see also* Appendix
- Transponder, 122, 123; *see also* Tracking
- United States Air Force
 - Space Track Research and Development unit, 121
- United States Navy
 - Space Surveillance Facility, 121
- Universe, 8, 9, 10, 30, 33
- Van Allen radiation belts, 29, 129
- Vanguard, 133
- Venus, 55, 77; *see also* Mariner
- Voltages, 86, 93
- Voyager, 54
- Weather (Earth), 12
- Word; *see* Computer, Binary code
- Xenon gas tube; *see* Laser, 140

ABOUT THE AUTHOR

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